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PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

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DEVELOPMENT OF THE CONTINUOUS PACK-HEATING FURNACE*

By John A. Hunter†

With the introduction of modern methods of rolling thin sheets it became necessary to develop a furnace to heat the material satisfactorily and economically. In order that the problem may be better understood, a brief description of the old and new methods of rolling will be given.

In the old method bars eight inches wide are received from the steel-mill, the length and thickness of the bars being varied to suit the desired finished size. In rolling tin-plate, in the first operation, known as roughing, the bars are rolled singly for several passes; they are then matched and after several passes are doubled and known as "fours." The fours are reheated, given several more passes and doubled again, after which they are known as "eights." The eights are reheated and rolled to the finished gage and length. The heating is done in furnaces of the "in and out" type; the furnaces for heating the bars being called pair furnaces and the furnaces for heating the fours and eights being called sheet furnaces. All the rolling is done consecutively on standard two-high mills.

In rolling sheet-mill products the operation is similar, except that after roughing the pieces may be matched into packs of either threes or fours. They may be finished with one reheating, or may be reheated twice as is done in tin-mill practice.

In the new method either bars or slabs are used. Bars are rolled on separate trains of standard roughing mills into pieces which are then matched into packs of threes or fours. Slabs are rolled into strips on continuous mills, of which there are several types in operation, the strips being cut into lengths and combined into packs of threes or fours.

As reheating packs twice in the same furnace is the most difficult, the development of a furnace to take care of this operation is described. After considering various methods of heating the packs of fours and eights it was decided that the furnace should be of the continuous type. With that type the packs could be handled more efficiently and,

*Presented January 22, 1928. Received for publication February 1, 1929.
†Assistant Chief Engineer, American Sheet and Tin Plate Co., Pittsburgh.

in addition, the fours could be kept away from the mill standing where their delivery would interfere with the rolling and doubling operations.

The principal furnace requirements are:

1. The packs of fours and eights must be uniformly and thoroughly heated to a temperature of about 1360 degrees F.

2. The surface of the packs must be free from deposits of tar, ashes or other foreign matter.

3. The surface of the packs must not be scaled.

4. The surface of the packs must not be scored by the conveying apparatus.

5. The furnace must be capable of satisfactorily heating alternate heats of cold fours and reheating hot eights.

As furnace conditions are more easily controlled with a gaseous or liquid fuel than with coal direct fired, and, as raw producer gas was available at the furnace site, it was decided to use raw hot gas with burners, thereby avoiding the expense of installing and operating a gas-cleaning plant. Burners were considered necessary in order to control furnace atmosphere, temperature, and pressure.

The original furnace, shown in Fig. 1, was 30 feet long and 42 inches wide inside the brickwork. The hearth consisted of revolving

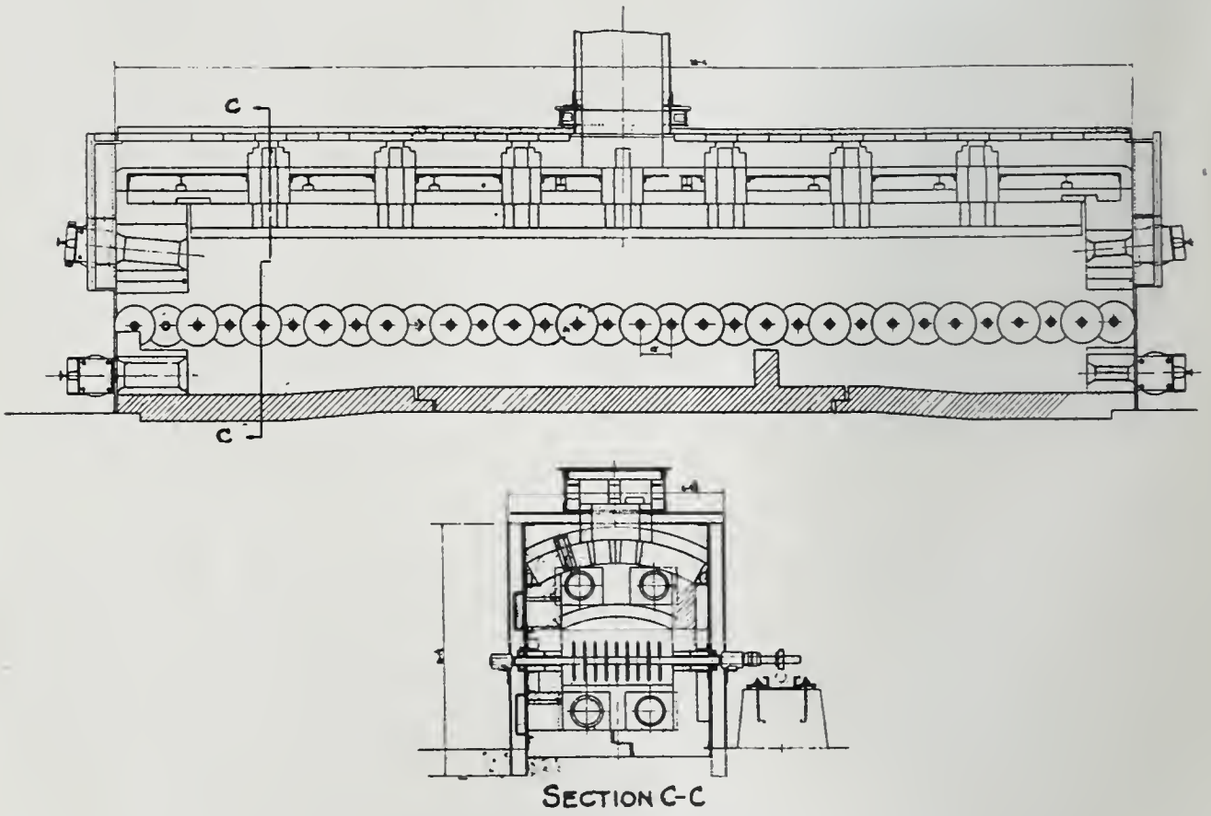

Fig. 1. Original Furnace.

alloy disks, carried on 32 shafts spaced 12 inches from center to center; a staggered disk arrangement being obtained by mounting alternately four and five disks per shaft. Both shafts and disks were made of alloy steel containing 18 per cent. chromium. The disks were of the split pressed type 1/8 inch thick and 16 inches in diameter, the pressed flanges being used for treads. The shafts were solid and three inches in diameter. Eight burners were used, four at each end of the furnace, two being located above and two below the disks. It was thought that eight burners were more than would be required, but they were provided so that any combination of top and bottom burners at either or both ends could be used to secure the furnace conditions desired. With either top or bottom burners alone in service, the furnace temperature could not be balanced and it was necessary to use some bottom and some top burners to obtain satisfactory heating. The burners themselves were not satisfactory, as the top burners deposited soot and tar on the packs; it was also very difficult to keep the burners free from soot and tar.

In order to get away from these troubles it was decided to abandon direct firing over the packs and to try a different burner. The burner used was of the so-called Venturi type with the air for combustion aspirating the gas as illustrated in Fig. 2. The combus-

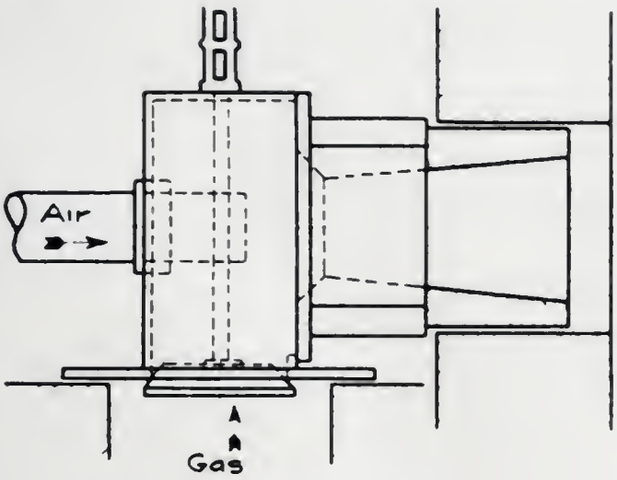

Fig. 2. Burner.

tion chamber is relatively small and is kept under pressure. Due to the high velocity of the gases leaving the burner there is a tendency for the gases to carry to the end of the combustion chamber. To overcome this and to obtain proper distribution of the gases in the heating chamber, the opening between the combustion chamber and

the heating chamber was made large at the burner end and progressively smaller to the other end. With this arrangement proper furnace conditions and satisfactory heating were obtained, but the furnace did not have sufficient capacity to heat both the fours and eights satisfactorily at the required rate. When the furnace was forced to heat the cold fours, the eights were too hot. To prevent the eights being overheated and to increase the capacity, the length of the furnace was first increased to 34 feet and then to 38 feet. This length of furnace gave quite satisfactory results. The final form of the furnace is shown in Fig. 3-5.

During the development of the furnace it became evident that preheated air would be of material assistance in producing better combustion and in preventing the accumulation of tar in the burners. A

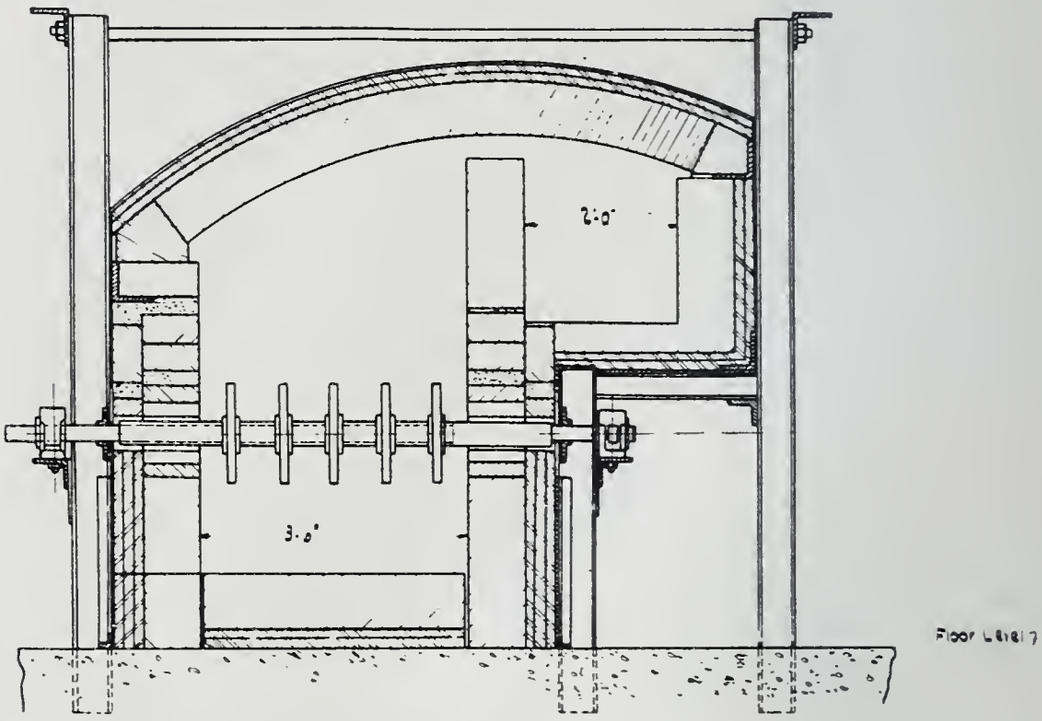

Fig. 3. Final Furnace.

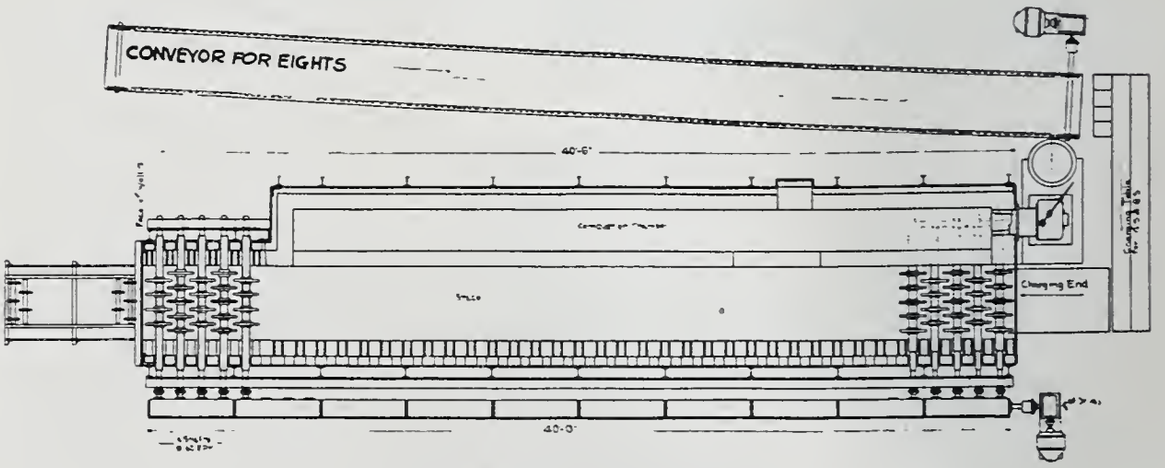

Fig. 4. Final Furnace.

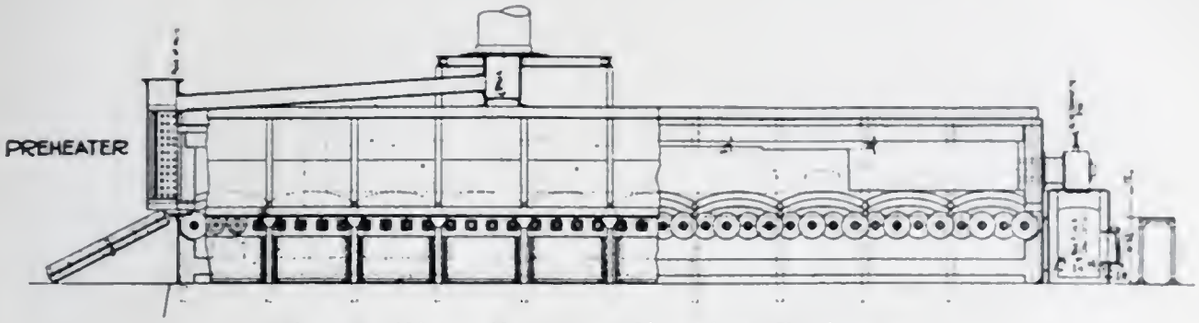

Fig. 5. Final Furnace Showing Preheater.

preheater (Fig. 5) was designed and added. The cold air enters near the top of the preheater and, after making three passes, is delivered to the burner at a temperature of 500 to 550 degrees F. The first preheater was of the tubular type, but a plate-type preheater was later tried and is giving satisfactory results. An interesting feature of the preheaters is the addition of a separate passage for the induced cold air, thus reducing the dilution of the hot gases from the furnace. This passage also makes the front of the furnace comparatively cold, thereby improving the working conditions for the men.

Illinois coal of the following average proximate analysis is used for making the producer gas:

Volatile matter	33.37 per cent.
Fixed carbon	49.92 per cent.
Ash	16.71 per cent.
Total moisture, determined separately	10.26 per cent.
Sulphur, determined separately	2.70 per cent.
B.t.u., dry	11,840 per pound

Attention is called to the high sulphur content of the coal, which varies from two to five per cent. The sulphur in the producer gas, together with the temperature and reducing atmosphere carried in the furnace, is believed to have caused the failure of some of the alloys tried, due to the action of the sulphur on the nickel.

The original shafts and disks were of chrome alloy, the composition of which is indicated at *a* in Table I. After about seven months' operation oxidation had progressed to such an extent that these shafts and disks had to be replaced. This led to the use of shafts and disks of the composition shown in *b*. The alloy with 15 per cent. nickel and 30 per cent. chromium was successful, but the alloy with 15 per cent. chromium and 30 per cent. nickel failed. The shafts that failed were removed and replaced by shafts of another design in which the disks

TABLE I. DEVELOPMENT OF SHAFTS AND DISKS (DRY)

	Analyses			
	Shafts	Disks	Sleeves	Comment
a.	18 Cr. 0 Ni.	18 Cr. 0 Ni.	None used	Removed after seven months, due to oxidation
b.	15 Cr. 30 Ni.	15 Cr. 30 Ni.	None used	Removed, due to sulphur attacking nickel
	30 Cr. 15 Ni.	30 Cr. 15 Ni.	None used	Successful
c.	21 Cr. 12 Ni.	30 Cr. 0 Ni.	None used	Hubs of disks form sleeves over entire shaft Removed, due to mechanical weakness of disks
d.	21 Cr. 12 Ni.	30 Cr. 7 Ni.	None used	Hubs of disks form sleeves over entire shaft Successful
	17 Cr. 32 Ni.	30 Cr. 7 Ni.	28 Cr.	Sleeves over shaft used Successful

were made integral with the hubs, which interlocked with each other, forming a sleeve for the full length of the shaft. The space between the hubs and the shaft was packed with an insulating material to prevent the gas from coming into contact with the shaft. The shaft contained 12 per cent. nickel and 21 per cent. chromium; the disks and hubs 30 per cent. chromium with no nickel. This design developed mechanical weakness, and for this reason the disks were replaced with disks of better design, containing 30 per cent. chromium and seven per cent. nickel. This design and composition proved to be satisfactory.

A different design which is also successful provides sheaths to protect the shafts. The sheaths are 28 per cent. chromium; the disks seven per cent. nickel and 30 per cent. chromium; and the shafts 32 per cent. nickel and 17 per cent. chromium.

On account of the intermittent operation of the furnace conveyor train, exposing only one side of the shafts and disks to the direct flame for an appreciable length of time, it was thought that water-cooled shafts might be an improvement. Accordingly, water-cooled shafts were installed in some furnaces. However, data taken as to the quantity of water used and its rise in temperature showed a fuel loss—due to heat carried away in the water—of approximately 100 pounds of coal per furnace per hour. For this reason, and also because dry shafts of proper design and composition were giving satisfactory service, it was decided to use dry shafts for future furnaces. The designs of some of the shafts and disks now in operation are shown in Fig. 6. In the design A, the shaft and the disks contain 15 per cent. nickel, 30 per cent. chromium, and 0.35 per cent. carbon. In B, the shaft is

of ordinary seamless steel tubing, while the disks and sheaths contain seven per cent. nickel and 30 per cent. chromium. In C, the shaft is of ordinary seamless steel tubing, while the disks contain 15 per cent. nickel and 30 per cent. chromium. D is a solid shaft with 32 per cent. nickel, 17 per cent. chromium, and 0.22 per cent. carbon; the sheath contains 0.5 per cent. nickel, 28 per cent. chromium, and 0.25 per

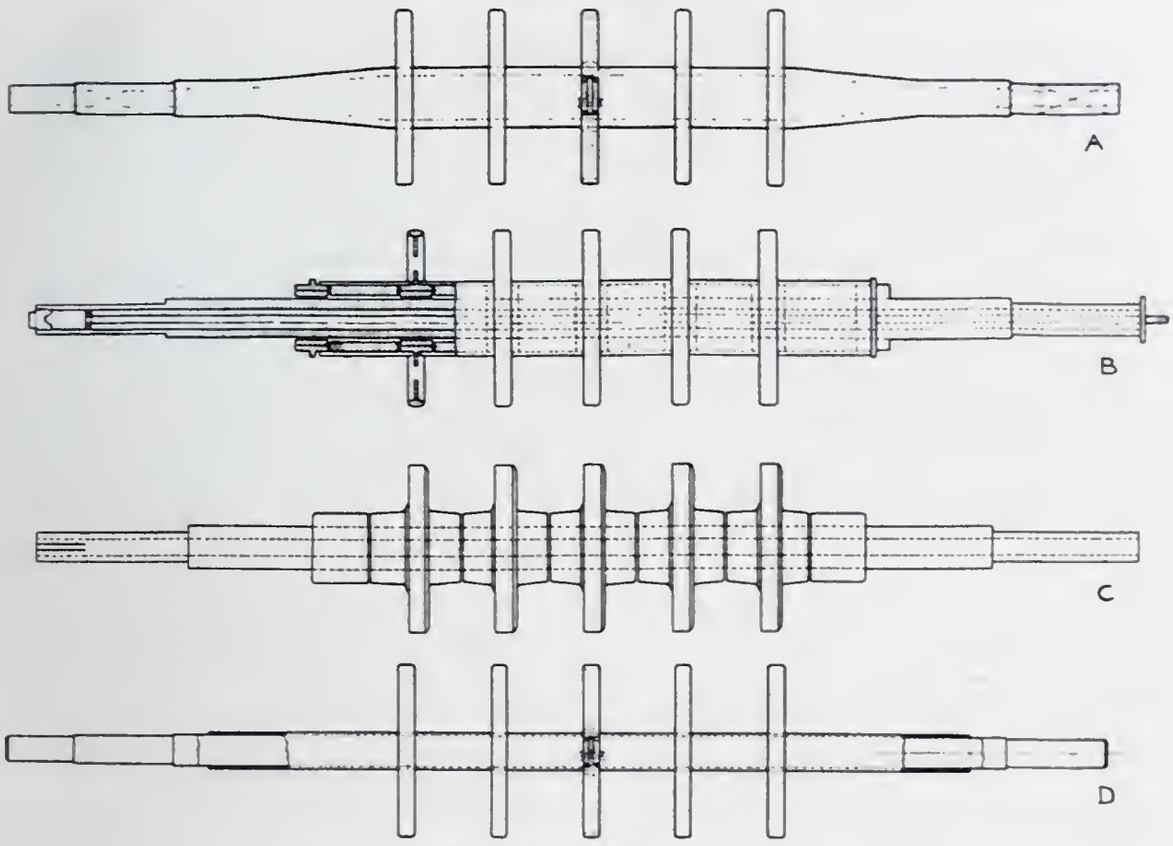

Fig. 6. Assembly of Shafts and Disks.

cent. carbon; and the disks contain seven per cent. nickel, 30 per cent. chromium, and 0.22 per cent. carbon.

A 7.5-horse-power motor operating through a speed-reduction gear drives a shaft running parallel with and alongside the hearth of the furnace, the shaft being supported by roller-bearings. Power is transmitted to each of the 40 roll shafts by means of worm gears. These shafts revolve at a speed of approximately 16 r.p.m. The bearings on the original furnace were arranged to take care of normal expansion, but it was found necessary to reset them to allow for the permanent growth of the dry shafts, which amounted to as much as ¾ of an inch.

The cold fours are delivered from storage to the rear of the furnace by an overhead traveling crane. The eights are returned to the

rear by means of a conveyor operating between the hot mill standing and the charging end of the furnace. The conveyor shown in Fig. 5 carries the packs of eights from the mill standing to a conveyor table on a level with and adjoining the dry pinch rolls. These rolls also serve as a gate or seal to close the furnace from the outside air. They are divided in the middle, a space about 2½ inches wide being provided at this point for observation of furnace conditions.

A heat of fours or eights, consisting of approximately 30 packs, is charged and conveyed through the furnace on the disks to the discharge end, about one-half of a heat being in the furnace at any one time. The packs are charged one at a time and as close to each other as possible so as to keep the entire hearth covered.

It is necessary to have the packs discharged from the furnace quickly, and only one at a time. In addition, the pack following the one discharged must be stopped before it reaches the door to prevent it from having a cold end. This is accomplished by stepping up the speed of the last four rolls to 60 r.p.m. and making the discharge of the packs semi-automatic. To discharge a pack, the roller presses a button located at the mill standing. This starts the motor driving the rolls, and discharges a pack to the gravity conveyor which delivers it to the mill standing where it is within easy reach of the roller. The rolls continue to revolve until the next pack comes on the high-speed rolls, where it strikes a trigger that stops the conveyor roll train.

An automatic temperature control has been developed to keep the temperature of the furnace within the desired limits. Ordinarily this is between 1450 and 1480 degrees F., to secure a pack temperature of 1350 to 1380 degrees F.

The temperature control consists of a thermo-couple located in the side wall of the furnace about ten feet from the charging end, acting through a potentiometer type of control to operate a solenoid that, in turn, opens and closes a butterfly valve in the air inlet to the burner. As the air aspirates the gas, this effectively controls the supply of both air and gas and gives a positive control of the furnace temperature. Sufficient leakage space is provided past the butterfly valve to give a moderate amount of heat, even when the valve is closed.

Fig. 7 shows the comparative furnace temperature secured with both hand and automatic control. The introduction, into the furnace, of alternate heats of hot and cold packs is responsible for the periodic

waves in the temperature when the furnace is under hand control. With automatic control, the amount of fuel supplied to the furnace is varied to accommodate the change from hot eights to cold fours and vice versa. The correct amount of fuel is supplied to keep a constant furnace temperature at all times, thus insuring uniformly heated packs. The same results could possibly be obtained by hand control if

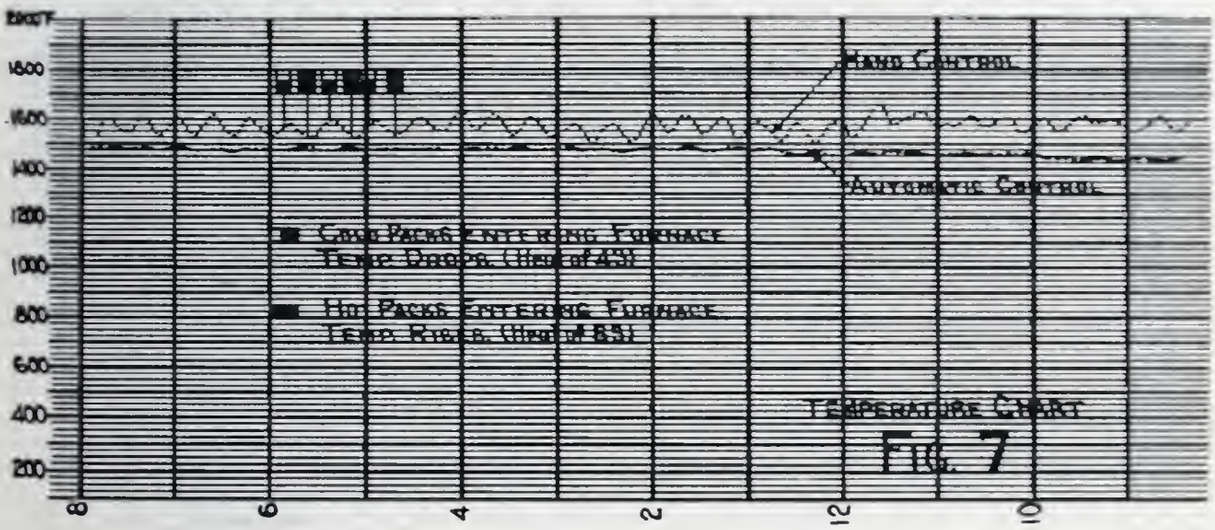

Fig. 7. Temperature Chart.

the heater gave his entire attention to the manipulation of the valves; however, this is impractical. For this reason, it is believed that the temperature control accomplished by hand, as indicated in Fig. 7, is representative of average conditions with hand control.

Although this furnace was developed primarily for the heating of packs coming from a continuous mill, it is being used for heating similar material produced on other types of mills.

It is felt that the devolopment of the continuous pack-heating furnace represents a decided advancement in the art of heating. The outstanding feature of this furnace is the continuously uniform and thorough heating of the packs.

With packs uniformly heated, it is possible to keep the mills in better condition and produce a better product. It is also unnecessary to have a skilled heater to operate the furnace so that the heater, who previously has had a hard, hot, and exacting job, can be eliminated from the mill crew. This makes it easier, particularly in the hot months, to maintain crews and thus obtain maximum output from the mills at all times.

CLEANING OF COAL IN THE BITUMINOUS FIELDS OF PENNSYLVANIA*

By J. B. Morrow† and J. R. Campbell‡

It is the purpose of this paper to set forth the various types of coal-cleaning equipment used in the bituminous fields of Pennsylvania, and the tonnages handled hourly, based on the rated capacity of the plant as furnished by the manufacturers. The list given, due to present market conditions, naturally contains some idle plants and possibly some abandoned plants. It shows the potential coal-washing capacity of the various equipments.

The equipment used consists of pneumatic tables, wet tables, jigs, launder washers (as exemplified by the "Rhéolaveur"), the Menzies "hydro" separator, and Chance sand flotation. All the different types of dry tables are being used—the Arms table, sold by the Roberts and Schaefer Company, Chicago; the Sweeney table, as developed by Heyl & Patterson, Inc., Pittsburgh; the Y-table sold by the American Coal Cleaning Corporation, Welch, W. Va.; and the Peale-Davis table, as developed by Mr. E. K. Davis, St. Benedict, Pa.

The Arms table is a reciprocating table, operating on a sized coal, generally recirculating the middlings to the main feed. The Y-table is a reciprocating table, operating on a sized product also, although it is claimed by the manufacturers that the sizing does not have to be as close as in the older tables. The Heyl & Patterson table is a reciprocating table operating on sized products with a return of the middlings to the main feed. The latest development of the Peale-Davis table is a reciprocating table, operating on unsized feed from four inches down, the middlings and refuse being taken off and treated separately on a secondary table. The deck of this table is much longer and wider than the other types referred to and consequently the capacity is higher.

A study of the literature develops the fact that the first dry cleaning was done on seeds and grains and it is only within the last decade that the principle of air separation has been applied to coal cleaning. This development has been described fully in the literature extant and need not be reviewed here.

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For dust recovery from pneumatic cleaning, two types of collectors are being used—cyclone collectors and bag-house collectors. Some of the newer air plants are using bag-house collectors and thereby reducing the dust in the mill. In the Peale-Davis system of dry cleaning, the dust is collected by means of an expanding air chamber over the table and requires no additional accessories.

In the Pennsylvania bituminous fields, the only wet tables that have been installed to any great extent, are the Campbell bumping tables and the Deister tables, the former being manufactured by Heyl & Patterson, Inc., Pittsburgh, and the latter by the Deister Machine Company, Fort Wayne, Ind. There are a few installations of the Overstrom tables in connection with jig plants built by the Link-Belt Company. These tables are an integral part of the washery and generally operate on the hutch material.

As has been pointed out in the literature on the subject, the Campbell bumping table has had a long and useful career, particularly in the Johnstown district. The newer Campbell bumping table is installed by the Rochester and Pittsburgh Coal Mining Company, and due to a change in the deck features, has a greater capacity than the older tables.

The Deister machine table has been quite extensively installed in the Greensburg and Blairsville fields, as will be noted from the tabulation at the end of this paper. This table is a development of metallurgical practice. In fact it may be stated here that all wet concentrating tables of this type are the offspring of the old Wilfley table.

The various types of jig listed are the Stein-Borecke, Luhrig, Pittsburgh, Foust, and very lately the Baum jig. The Foust three-compartment jig has perhaps had the widest application in the Pennsylvania bituminous field. This jig was sponsored by the Link-Belt Company, which has lately taken on the manufacture and sale of the Baum jig, now known as the Simon-Carves jig.

The Baum jig is an old jig and has had a wide application in Europe. It might be well to say something about the specific features of this type of jig. It is an overflow compartment jig with air as the control on the different compartments, making it possible to clean fine sizes better than the older types of jigs, due to decrease in suction on the down stroke. It is perhaps the most modern development in jig

washing, and it handles an unsized feed very satisfactorily. The Baum jig at the Eliza plant of the Jones & Laughlin Steel Corporation is an example in the Pittsburgh district.

Chance flotation system is found at the Mt. Union plant of the Madeira Hill Company. It washes coal from four inches down to approximately 3/8 inch, below which size the product is by-passed dry. The Chance method depends upon the formation of an artificial specific gravity due to agitation of a fluid mass of sand and water. This has frequently been described in print.

The "hydro" separator is an upward-stream washer. It operates most satisfactorily on a sized feed, and the application in the Pennsylvania field can be followed by the installations now being made for the Berwind-White Coal Mining Company at Windber, Pa.

The launder type of washer is represented in the Pennsylvania bituminous field by the installations of the Pittsburgh Coal Company. This is the "Rhéolaveur" system of washing, which is the latest development of the older types. The fundamentals of this system of washing are natural classification in a flowing stream of water, return of the middling products as a regulating feature, and simplified draw-offs by means of "Rhéo" boxes. The "Rhéolaveur" is the highest type of launder washer and is very flexible in operation.

In all wet washing systems there is the problem of sludge recovery and drying of the wet washed coal, just as there is the dust problem in pneumatic cleaning. Perhaps the rational way of handling wet washed coal is to recover the slimes in a Dorr tank or an equivalent, and possibly aid dehydration by filters or the application of heat. The intermediate coal, say from 1/2-inch to 28-mesh coal, may be centrifugally dried in approved types of driers now on the market.

The following is a summary of installations:

Type	Tons per hour
Dry tables	3080
Wet tables	2150
Jigs (all types)	720
Chance flotation	300
"Rhéolaveur"	1100
Total	7350

This total of 7350 tons per hour consists of a commercial capacity of 3060 tons per hour, and a metallurgical capacity of 4290 tons per hour.

In regard to the above tabulation, it must be noted that the "Rhéolaveur" systems at the three plants of the Pittsburgh Coal Company (Champion, Warden, and Banning) handle 1100 tons per hour, but the operation is in two shifts. In the tabulation on jigs and tables, it must be borne in mind that some of the plants are in continuous operation, representing the regular mill practice of 24 hours a day. In the Pittsburgh district the Jones & Laughlin Steel Corporation operates on such a basis and the tonnage is 430 tons per hour for 24 hours. In the commercial plants the operating day is usually eight hours.

For the reasons stated above, it is somewhat difficult to estimate the total tonnage of coal cleaned in Pennsylvania by wet and dry methods, but it will probably aggregate 18,000,000 or 20,000,000 tons of coal annually.

On an annual production of 200,000,000 tons of bituminous coal in Pennsylvania, it is thus seen that nine per cent. of the total production is now being mechanically prepared for either metallurgical or commercial purposes. This figure compares very favorably with the present proportion of mechanical cleaning in the United States, which is approximately six per cent. of the total annual production.

The following is a list of coal cleaning plants in Pennsylvania:

DRY TABLES

Name of company	Location	Type of equipment	Tons per hour	Uses
Humphries Coal & Coke Company..	Greensburg	Y-table	20	Metallurgical
Davis Coal & Coke Company.....	Boswell	Heyl & Patterson	175	Commercial
Ebensburg Coal Company.....	Colver	Heyl & Patterson	35	Commercial
Berwind-White Coal Company.	Houtzdale	Heyl & Patterson	125	Commercial
Berwind-White Coal Company.....	Windber	Arms table	400	Commercial
Berwind-White Coal Company	Windber	Arms table	400	Commercial
Pittsburgh Coal Company.....	Library	Arms table	325	Commercial
Hillman Coal & Coke Company.....	Jerome	Arms table	300	Metallurgical
Portage Coal Mining Company.....	Portage	Peale-Davis	200	Commercial
Carrolltown Coal Company.....	Spangler	Peale-Davis	200	Commercial
Peale, Peacock & Kerr.....	Glen Richey	Peale-Davis	200	Commercial
Peale, Peacock & Kerr.....	Winburne	Peale-Davis	300	Commercial
Cherry Tree Coal Company.....	Emeigh	Peale-Davis	200	Commercial
Youngstown Sheet & Tube Company.....	Brier Hill	Peale-Davis	200	Metallurgical
		Total	3080	

WET TABLES

Bethlehem Steel Company	Johnstown	Campbell bumping tables	400	Metallurgical
Bethlehem Steel Company	Johnstown	Campbell bumping tables	400	Metallurgical
Vintondale Colliery Company	Vintondale	Campbell bumping tables	125	Metallurgical
Lackawanna Steel Company	Wehrum	Campbell bumping tables	275	Metallurgical
Buffalo & Susquehanna Coal & Coke Company	Tyler	Campbell bumping tables	175	Metallurgical
Rochester & Pittsburgh Coal Company	Ernest	Campbell bumping tables	60	Metallurgical
Rochester & Pittsburgh Coal Company	Ernest	Campbell bumping tables	200	Commercial
Potter Coal & Coke Company	Coral	Deister tables	150	Metallurgical
Keystone Coal & Coke Company	Crabtree	Deister tables	125	Metallurgical
Keystone Coal & Coke Company	Hannastown	Deister tables	140	Metallurgical
Keystone Coal & Coke Company	Luxor	Deister tables	100	Metallurgical
		Total	2150	

JIGS

Jones & Laughlin Steel Corporation	Aliquippa	Foust jigs	350	Metallurgical
Jones & Laughlin Steel Corporation	Eliza Furnace	Baum jig	80	Metallurgical
Keystone Coal & Coke Company	Salem	Foust jigs and Overstrom tables	150	Metallurgical
Saxman Coal Company	Latrobe	Pittsburgh jig	40	Metallurgical
Graceton Coal & Coke Company	Graceton	Stein-Borecke jigs	100	Metallurgical
		Total	720	

WASHERS

Pittsburgh Coal Company	Champion	"Rhéolaveur"	500	Metallurgical
Pittsburgh Coal Company	Warden	"Rhéolaveur"	300	Metallurgical
Pittsburgh Coal Company	Banning	"Rhéolaveur"	300	Metallurgical
		Total	1100	

CHANCE FLOTATION

Madeira Hill Company	Mt. Union	Sand flotation	300	Commercial

The following table indicates the installed capacity of various systems:

DRY PROCESS

	Tons per hour
American Coal Cleaning Corporation	20
Heyl & Patterson, Inc	335
Roberts and Schaefer Company	1425
Peale-Davis	1300
Total	3080

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WET PROCESS

Heyl & Patterson, Inc.	1635
Deister Machine Company	515
Pittsburgh Coal Washer Company	40
Link-Belt Company	580
"Rhéolaveur" (double shifts)	1100
Chance flotation	300
Miscellaneous	100
Total	4270
Grand total	7350

DISCUSSION

CHARLES ENZIAN:* Mr. Campbell spoke of two types of dust collectors—cyclone and bag. We are installing a third type, the Pangborn dust arrester—a screen design.

I think Mr. Campbell's figures as to the total tonnage—that is the percentage of the tonnage cleaned by wet and dry systems in the United States—are very close to the figures that I compiled. Roughly three per cent. of the total output of the bituminous coal in the United States is air cleaned. I think the wet cleaned coal is about the same proportion.

R. W. ARMS:† Did you prepare these figures to segregate metallurgical coal from that used for steam purposes and other purposes?

J. R. CAMPBELL: The total commercial capacity is 3060 tons, and for metallurgical uses 4290 tons an hour.

R. W. ARMS: It is interesting to note that in the early days coal cleaning was confined almost entirely to metallurgical purposes, whereas now there is an increasing tendency to clean for other purposes.

*Mining Engineer, Berwind-White Coal Mining Co., Windber, Pa.
†Manager, Coal Cleaning Department, Roberts and Schaefer Co., Chicago.

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CHARLES ENZIAN: For information I would like to know if Mr. Campbell has approximate figures as to the percentage of sludge recovered, or present, in wet preparation.

J. R. CAMPBELL: I should say that it all depends on the character of the coal you treat. If you have a soft, friable coal such as is in the Pocahontas field and the central fields of Pennsylvania there is considerable sludge. I mean by sludge, fines below 48 mesh. In the Pittsburgh seam and in the harder coals the percentage of sludge is much lower. Giving an offhand figure on the Pittsburgh coals with which I am most familiar I should say that the percentage of fines below 48 or 28 mesh is anywhere from three to five per cent. I would rather you would consult Mr. Morrow on that. He is getting experience right now.

CHARLES ENZIAN: In a discussion of this kind, of course, it is of very great interest to engineers and operators to know something relative to costs of installation and operation. I do not know whether Mr. Campbell is prepared to give such figures, but they would be very interesting. What is the cost per ton per hour capacity for installation and operation of wet systems?

J. R. CAMPBELL: I would not like to go too much into that at this time. I am not an engineer in the full sense of the word and any statement I might make might not be exactly correct. But I would say that the simplest type of commercial washing plant that could be put in would run about $400 per ton per hour. If you have to go into sludge recovery and dry the fine wet products mechanically, it would run considerably more than that. I am speaking of the washery, not the complete preparation plant. As to the cost of operation, I have never thought it best to make any claims that you could wash coal for nothing or nearly nothing. According to the best figures I am able to set up, the coal will cost from seven to 10 cents a ton to clean, and that figure will probably include depreciation charges but not conversion cost, which is the loss of input. I may add that the washing equipment is only a small part of the complete job—probably not over 25 per cent. of the total cost.

L. O. LOUGEE, *Chairman*:* Mr. Arms, can you give us some figures on that?

R. W. ARMS: I think Mr. Campbell's figures are as nearly correct as anyone could give. There have been washing plants built that cost as high as $1800 per ton hour in first cost. They were put in for special uses and because there were special problems involved in the cleaning process. I doubt if any have been built for less than $400 per ton hour in first cost, where the figures are based on the actual tonnage of coal cleaned. Many factors enter into the problem. In the case of Pocahontas coal, where there is a high percentage of fine coal which does not need cleaning, the few sizes which are dirty can be cleaned with a plant having a low first cost. For example, if the egg-, nut-, and pea-coal are the only sizes that need cleaning, the installation cost per ton would be much less than a plant for cleaning the fine sizes of coal. The same is true of the cost of operation. Mr. Enzian's problem at Windber was difficult because in order to reduce the sulphur to the point he wished to reach, it was found necessary to clean all the coal below ⅛ inch, the percentage of which is quite high.

It can be said that the dry cleaning process has reached the point where the first cost is comparable with any approved wet method. In former years, dry plants were expensive but because of increased capacity and simpler means of handling the air these costs have been reduced.

W. L. AFFELDER:† I should like to amplify the remarks in regard to the cost of the plant. No two installations are really comparable. We are constructing a dry cleaning plant at the present time that is going to cost about $1000 per ton hour; but we are going to try to do some things which a large number of plants might not attempt. We have certain problems peculiar to the installation which would not be found elsewhere, and for that reason our cost per ton hour might be higher than at another plant, yet another plant may have a more difficult problem than we have.

As far as the expense is concerned, it is hard to justify the expense of either wet or dry cleaning for a slight improvement in

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†Assistant to President, Hillman Coal & Coke Co., Pittsburgh.

product. To express it in more homely terms, unless you can make a silk purse out of a sow's ear, it is hard to justify any great expenditure for merely making a better ear. In other words, if you can convert steam coal into metallurgical coal, the expense is probably justifiable in a great many cases; but in a good many cases it is a question whether a slight improvement which will not bring with it an increase in selling price will justify any large expenditure.

J. R. Campbell: In line with Mr. Affelder's remarks, I might say that the cost of washing can be more easily justified in intercompany business than in commercial business. It is comparatively easy to justify the cost of washing coal where the fuel is to be used in the manufacture of pig-iron. This comes about by a decrease in the cost of operation of the furnace. Some figures in the Pittsburgh district run from 10 to 15 cents a ton of pig-iron for every one per cent. of ash reduction in the coke. That is quite a good figure when you consider that it is possible to reduce the ash at least three or four per cent. I think that side of the question is going to be discussed more and more in intercompany business, as Mr. Affelder undoubtedly had in mind.

W. L. Affelder: I think Mr. Campbell is entirely right. A large percentage of cleaning plants, either wet or dry, and especially the older wet plants, are at mines owned by steel companies using their own product. I had in mind more the question of investment in a commercial plant, because the commercial plant must get its investment back through commercial sales.

C. A. McIntyre:* What would be the percentage of increase of moisture in the finished product over the raw coal?

J. R. Campbell: With a very efficient wet washing job on coal four inches and under, and with efficient methods of drying, the initial moisture being within reasonable limits, you may have from two to three per cent. more moisture in the finished product than in the initial product. We are finding (I am taking the liberty of using some figures which I happen to have) in the wet washing job at the

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Champion plant, 1½ inches by ⅜ inch drains down to about 2½ per cent. by natural drainage. By drying the sludge centrifugally, and by heat drying the ⅜ inch by 48 or 28 mesh centrifugally, the total moisture will be in the neighborhood of five per cent. on coal four inches and under. You can figure two to three per cent. more moisture in the finished product than in the initial product. You can dry by heat and make it entirely dry, of course. You can make the coal clean and nearly dry by modern wet processes.

W. L. Affelder: Is Mr. Campbell prepared to give any figures in regard to ash and sulphur?

J. R. Campbell: If you will take them as unofficial figures I can give the ash in the coal going to market. The first cargo of Pittsburgh slack coal reached its destination with an ash content of 7.04 per cent. on an ash standard of seven per cent. The moisture was 3½ per cent. This plant is a commercial plant and not designed to reduce sulphur. I do not know that they have even made any sulphur determinations in the Champion plant; but at the Warden and Banning plants it is a metallurgical job and they anticipate a sulphur reduction to 9/10 of one per cent. in the washed coal at these plants. I am sorry I have no figures on sulphur in the Champion plant because that is a commercial plant. In the raw coal, the sulphur runs from 2½ to three per cent. in the slack coal from certain mines.

Charles Enzian: From Mr. Campbell's paper I got the impression that the wet process was confined to sizes above ⅜ inch. I do not know whether that is correct.

J. R. Campbell: No, I did not wish to give that impression. I was speaking of a complete wet washing job. Where natural drainage is used on the top sizes down to ⅜ inch, or above ⅜ inch, I made the statement that natural drainage on 1½ inches by ⅜ inch was down to 2½ per cent. moisture. The ⅜ inch to 48 or 28 mesh is dried in centrifugal driers. If you want coal as dry as you start with, you have to apply some heat to it. A figure of two or three per cent. more than the initial moisture is about the best that can be done by the most approved methods of wet washing and drying on coal four inches and under.

CHARLES ENZIAN: What is the largest size that you treat to get two to three per cent.?

J. R. CAMPBELL: We are not yet washing the coal under four inches; only from 1½ inches down. About 2½ per cent. is the result of natural drainage of coal 1½ inches to ⅜ inch. What happens when you get up to four inches is that the moisture will probably be a little less.

CHARLES ENZIAN: What I think Mr. McIntyre had in mind was to get an idea as to what the added moisture would be if the cleaning were entirely by the wet process.

J. R. CAMPBELL: You can safely figure two to three per cent. more than the initial moisture, whatever that is. If you have two or three per cent. moisture in your feed coal, as in this district, you can figure five or six per cent. in the finished product, unless special attention is given to heat drying of the slimes.

C. H. DODGE:* For metallurgical purposes, is the margin of economy between cleaning costs and the sales realization favorable to washing the fines and adding this moisture increase to the plant output, or by-passing these fines and absorbing the higher ash of the fines with the clean coal output?

J. R. CAMPBELL: I do not think the question of moisture in metallurgical practice is as important as in commercial practice. Psychology is against the shipment of wet coal. In fact, there is a great deal of psychology in it. It is damp coal; you can not argue against that. That necessitates the payment of additional freight on the moisture; but you have clean coal to offset that. Now, in metallurgical practice, as far as I am able to determine, the moisture is not so important. We know that coal seven to nine per cent. moisture is being charged into by-product ovens every day in the Johnstown district. Down south they are charging wet washed coal into coke-ovens. I think five to six per cent. moisture in a coke charge is a good figure.

*Assistant Engineer, H. C. Frick Coke Co., Scottdale, Pa.

C. H. Dodge: How large a percentage of moisture is desired in the raw coal charged to the by-product ovens? I understand there is a definite per cent. of moisture wanted.

J. R. Campbell: Between five and six per cent. In English practice they say when you go below six per cent. there is not enough water. When you have 12 to 15 per cent., that is no good either. It impairs the oven walls and the cell structure. It cuts the output. When you get down to five and six per cent., it increases the ammonia yield and has a lot of pleasing sides to it, and they have often told me at Johnstown that if the coal did not carry five or six per cent. of moisture they would add water. In the Pittsburgh district I believe the practice is to add moisture to extra-dry coal. If you have a swelling coal you have to do something to keep down swelling. There are two ways to do it—put a high volatile, or shrinking, coal with it or add water.

W. L. Affelder: You say to keep down swelling?

J. R. Campbell: Yes.

C. H. Dodge: How does an increase in moisture in the coal charged affect the by-product yield?

J. R. Campbell: It increases the yield of ammonia. That is largely what water is added for in by-product ovens, and to keep down the formation of carbon in the oven chambers and walls.

R. H. Schaller:* With the addition of moisture in our coal, the ammonium sulphate yield will increase approximately two pounds per ton of coal charged over that of the use of the same coal charged dry.

J. R. Campbell: That is the answer right there.

R. W. Arms: The question is often asked, "What is wet coal and what is its effect on the by-product oven?" There is a current

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report based on inquiries sent to practically all of the coke-oven plants in the country and there is no general agreement as to the effect of any definite percentage of moisture on the ovens or the by-products, although the general opinion is that high moisture contents are not desirable.

As regards shipping, wet coal can be defined only as coal which will freeze in the railroad car. However, this percentage varies in different fields and can not be exactly evaluated. In trying to define wet coal as it offers difficulties to the air cleaning processes, we simply contented ourselves with pointing out that it is that coal which offers difficulties in screening. The difficulty of setting a fixed percentage of moisture for any purpose arises from the fact that coals have variable percentages of natural moisture. In northern Illinois there are coals which contain as high as 12 per cent. moisture and still are dusty. In the Pocahontas field and others the natural moisture is as low as one per cent.

The fact that the Champion plant or any other plant that has efficient drying facilities reduces moisture to two or three per cent. does not really answer the question, until the market that this coal reaches is taken into consideration. As a by-product coal, five or six per cent. is not only permissible, but in some cases desirable. In rail or barge shipments where the climate is cold it is only a question of how much moisture will cause the coal to freeze in the cargo in case there is a delay in unloading.

J. R. Campbell: I confirm the remarks of Mr. R. W. Arms. Regarding Illinois coal, I was with the United States Steel Corporation for a good many years, and during that time I had something to do with the washing plant in southern Illinois. That coal came out of the mine carrying seven per cent. moisture. We had a wet washing job and we added about three per cent. moisture. That coal was dry and dusty coming out of the mine, yet it carried seven per cent. initial moisture. It went to market with about 10 per cent. in it. I think Mr. Arms is also right when he says it is difficult to define wet coal. What is sauce for the goose is not always sauce for the gander in that respect. Coal that will not freeze in going to market, I would consider as dry coal. Just what figure that is nobody knows exactly. It depends on the character of the coal. Seven per cent. might not freeze

in some cases and five per cent. might freeze in other cases. We generally consider that coal with no free water in it will not freeze—say five or six per cent. moisture.

F. A. JORDAN:* Really, I came to listen and not to talk. Without going into the thing too much in detail, there has been an attempt made by our people to determine the relationship between moisture and ash.

J. R. CAMPBELL: That is, aside from the freight rate?

F. A. JORDAN: When it comes to the matter of freight rates, the moisture is just as much an inert as ash. If you remove one per cent. of ash in the cleaning plant, and replace with one per cent. of moisture you have the same freight rate. One thing that would influence freight rates would be the manner in which the coal was loaded. I believe that has not been touched on very much either here or in articles that have been written. If coal be loaded in a certain sequence with regard to size it will have certain draining features. For instance, if a coal in a washing plant is sized between four and two inches and loaded on the bottom of the car and another size two inches to one inch on top, and then the finer sizes on top of that for the purpose of free draining, such a loading scheme would allow shipment of coal with a minimum of freight and considerably under what it would be if the same run-of-mine were loaded as a mixture of sizes. The freezing would be quite different.

I started in to say that we had tried to set up the relative values between ash and moisture in the matter of using coal in by-product work. I have pointed out that with wet coal there are several things that are difficult. There are other things that are desirable; for instance, in loading coal, it would result in a smaller freight bill to have the coal weighed at destination instead of when dripping water at the plant. Any setting up of values must be a specific problem. There can be no general statement. In our problem we have arrived at one per cent. moisture as being the equivalent of about 0.7 per cent. of ash. In that determination there were about twenty different people involved. I would hardly like to say they were twenty experts, but

*Youngstown Sheet & Tube Co., Youngstown, Ohio.

they were involved in the different steps through which the coal passes from the mine to the final use in the blast-furnace as coke.

Just as I came in (unfortunately I did not hear all the discussion), there was something as to how much moisture was added to different coals. At the Mt. Union plant we made tests of the Chance sand flotation process. As most of you know, the Mt. Union plant was designed to screen out the dry 3/8-inch material, but in these tests the screens were taken away and everything was wet, to see what the performance would be. The coal at Youngstown had exactly one per cent. more moisture than the raw coal that was put into the plant. That shipment of course underwent drying during the period of shipment. That test included a trifle over 500 tons of coal and was large enough to give some indication of what drainage in shipment meant. It was shipped in the latter part of December and took about seventy hours to come from Mt. Union to Youngstown, and of that total there were only about twelve hours that were above the freezing point. The coal was not robbed entirely of its heat in the center of the car and there was no difficulty in unloading the coal on account of freezing.

That test was duplicated later by another test by another interest in which 200 tons of coal were involved, and upon arrival at the destination, which was Toledo, Ohio, the increase of moisture was about 0.8 per cent. over what it was when it was put into the plant. In this case the coal above 3/8 inch was not wetted.

Harry J. Lewis:* In discussing part of this moisture question over which we have some control we have overlooked rain or dry weather during transit, which sets up a variable over which you have no control. A car of coal in transit three days getting a good soaking and then freezing up will retain nearly all the moisture.

J. R. Campbell: It does not make any difference whether it is wet or dry to start with.

Charles Enzian: I do not know whether I am speaking out of turn or not; but so we will not go away with a confused impression, I wish to state that we went through a stage of about four years

*Consulting Engineer, Pittsburgh.

of experimenting before we decided what system was most suitable for our product. The statements of the relative moisture seem to be confined almost entirely to Pittsburgh coal. Those of us who have had experience with high-volatile and low-volatile—the Monongahela and Allegheny series—coals know there is a tremendous difference in the physical characteristics and chemical qualities of these coals. It will not do the engineer or operator very much good to listen to these figures unless they are predicated upon one of the two kinds of bituminous coal in this state. With coal of the Pittsburgh seam, the results of our experiments differ greatly from those we obtained in our low-volatile or lower productive measures of coal. The Allegheny series coal, or the coals of central Pennsylvania, absorb a great deal more moisture, or assimilate it. Capillary attraction is very much greater. For the same reason that coal is broken down in your preparation plant to a very greatly increased number of sizes, infinitely greater than in the Pittsburgh seam. It may surprise you to know that at some of the mines where mechanical loading devices are used, 70 per cent. of the product will go through a ⅜-inch mesh, whereas, in the Pittsburgh seam or the high-volatile coal, only about 30 per cent. passes through a ¾-inch mesh. Therefore the problem of added moisture is very much complicated in the former problem.

It may interest you to know that we have two dry cleaning systems of 400 tons per hour at our mines in western Pennsylvania. There is a good reason for dry cleaning, and the points I have stated constitute the reason for cleaning our coal dry. It seems that coal cleaning for the western part of this state has been used for metallurgical purposes principally. Of course, commercial requirements are deserving of attention also at this time. Our results of added moisture percentage due to the wet and dry systems are almost twice what Mr. Campbell states. Mr. Jordan stated that the increase in moisture in the test sample at the Mt. Union plant, shipped to Ohio, was approximately one per cent. I might say that our experience in tests of about 300 tons in that same plant gave us the same result; but there was an indeterminate factor in the problem. There was no way of determining how much of the product went out with the sludge. Mr. Jordan may have figures to show that, but from a sampling of the sludge that was leaving the plant the preparation loss amounted to considerably over one per cent. of the product. Mr. Jordan said

they experienced no difficulty in unloading their coal at its destination. We made our test in December. It took considerably more time to unload the wet cleaned cars at their destination that it takes to unload the dry coal. We found that we could not treat the 3/8-inch coal in the Mt. Union plant because there were at that time no facilities for dewatering that size at the plant. In our thorough investigation of the problem after those tests, and before deciding on another cleaning plant, we found that we could not possibly meet the conditions imposed upon us unless we cleaned the 3/8-inch size.

It may be interesting to know that in the No. 37 plant—which is the dry cleaning plant which has been operating over two years—the ash reduction of the raw product on some tables is 56 to 59 per cent., depending on the quality of the input, and the sulphur reduction is approximately 35 per cent. The refuse from the smallest size tables is about the same in ash and sulphur as in the foregoing figures. This will give an idea as to the importance of cleaning the smaller sizes. The speaker has stated that each cleaning proposition is an independent problem and, as Mr. Affelder says, it requires local consideration. First of all, you must have extensive laboratory and field studies of the cleaning problems. Some of our investigations have extended over a period of almost six years and we have not by any means found all the solutions. I think we are just about getting to a real starting point.

J. R. Campbell: I think Mr. Enzian has called attention to a very important thing and that is plant loss. I have seen some tests just recently where the plant loss was two to five per cent. That immediately introduces an element of doubt into any conclusion you may reach from the test. It is a very important factor. We do not know what it is or what effect it has on results unless we account for or measure it to see what it is. It may be dust and it may be sludge, or rock, or bone.

I wish to clarify another point Mr. Enzian brought up—that is, the washability of two given coals. We, who are acquainted with washing, know that the Pittsburgh coal is not as amenable to washing as the lower productive measures. In the Pittsburgh coal, it is very difficult to reduce sulphur, under the most favorable circumstances, more than 25 to 30 per cent. In extreme cases 35 to 40 per cent. may be eliminated by washing. Ash is more amenable to reduction than

sulphur. On the other hand, nearly all the lower productive measures are much more amenable to ash and sulphur reduction than the Pittsburgh coal. It is not uncommon to see 50 or 60 per cent. reduction in sulphur in some of the lower productive measures. If you have 2½ per cent. sulphur you can get it down to 1¼ per cent. without much trouble. I want to emphasize that. The lower productive measures are much more amenable to reduction in ash and sulphur than the Pittsburgh coal.

F. B. DUNBAR:* Is it not true that in the Pittsburgh seam of coal we do not get the crushing that we do in the upper Freeport measure of the central Pennsylvania field, and that this is the cause of fines rather than the method of cleaning?

J. R. CAMPBELL: Not altogether.

F. B. DUNBAR: I remember that at the Wehrum property it was necessary to crush all coal to ¼ inch, or under, before the sulphur could be removed to the extent necessary.

J. R. CAMPBELL: I agree that the lower productive measures in some cases may have to be crushed fine to free the sulphur.

F. B. DUNBAR: The coal from the Wehrum plant was moved by gravity into the draining pits and contained about 15 per cent. moisture. The coal remained in the pits from 48 to 72 hours and was loaded into railroad cars for the Buffalo plant, and in the winter season it was necessary to place the railroad cars in drying sheds where steam was used. It is quite a problem to wash coal from the central Pennsylvania field, and, due to its fineness, it takes up a large amount of moisture.

J. R. CAMPBELL: It has to be crushed fine. It ought to be crushed down to ½ inch, possibly ⅜ inch, to get the greatest ash and sulphur reduction; but crushing Pittsburgh coal to the same size does not always increase its washability. Is that your experience, Mr. Arms?

*General Superintendent, Hillman Coal & Coke Co., Pittsburgh.

R. W. Arms: Yes.

J. R. Campbell: That is my experience, crushing Pittsburgh coal fine does not help its washability to any great extent and multiplies the troubles from slimes. The proper thing to do with Pittsburgh coal is to wash it in large sizes at low gravity, with a second washing at high gravity. The usual gravity of washing the Pittsburgh coal with a two-product job is about 1.60 specific gravity. If you want a fine metallurgical coal you have to handle it in another way. If you wash at low gravity, 1.40 or 1.45 specific gravity, you will get a low ash and the highest sulphur reduction it is possible to get in a range of sizes up to four inches. It is only a question of engineering as to how you will handle the primary reject. There are several ways to do it. It is possible to get low-sulphur coal from the Pittsburgh seam by washing at low gravity and crushing and recleaning the primary reject. Fine primary crushing does not always help and it increases the difficulties. I used to think that fine primary crushing was necessary, but I have changed my notions completely.

F. A. Jordan: I am delighted that Mr. Enzian called attention to the fact that the figures submitted for moisture in the Mt. Union coal might be in error. It shows the danger in general remarks giving a few figures. From the Mt. Union plant, there is a discharge of a very fine silt that is wasted from the system. The determinations were rather hard to get. As nearly as we could determine, 0.92 of one per cent. of the coal escaped through that outlet. There is no doubt that if that material had been added to the coal it would have increased the moisture. In a test of that kind there are many difficulties involved; for instance, a very large proportion of the material you treat is always left in the corners of the testing plant, and that is not included in the figures as either coal or refuse. The fact of the test, stated bluntly, is this, that the float-and-sink determination upon which the test was made, which was based on 1.40 specific gravity, showed that we should have recovered 93½ per cent. The coal was weighed gross and the cars were weighed tare, both at Mt. Union and at Youngstown. The moisture in both cases was sampled, and on the dry basis we received and unloaded at Youngstown 91.1 per cent. of the total dry coal that was put into the plant. So you see there was some loss in the plant for which we could not account.

CHARLES ENZIAN: I might further substantiate Mr. Jordan's remarks concerning the difference between their product and our central Pennsylvania product. The material present in the sludge appeared to be about 1.2 per cent. of the total input, which indicates a sludge loss of 1.2 per cent. unless a thickener process is installed. Upon precipitation and drying out the moisture from that sample we found that 50 per cent. of it went through a 200-mesh screen. The average of this was about one per cent. lower ash than the cleaned product recovered from the plant. When I say that, I want it clearly understood that the ash reduction in the Mt. Union plant, in the sizes treated (two inches to 3/8 inch) compared as favorably with the laboratory study as could reasonably be found in a commercial run. It was a very excellent separation.

R. A. MITCHELL:* I did not expect to be called on. I just returned from a long trip and did not know this meeting was on until this morning and consequently I do not come prepared to enter into the discussion. I want to hear the others, and have been very much interested in what has been said here.

The Link-Belt Company is getting very excellent results from the Simon-Carves system as exemplified in the two plants which we now have in operation. These results can be easily obtained by any of you, as we will supply them to anyone interested. However, as regards getting into a discussion of the Simon-Carves system, I should like to be excused this morning.

W. L. AFFELDER: I think both the wets and drys will agree that the theory of coal cleaning, whether it be wet or dry, is practically the same, and that neither process will accomplish anything which a float-and-sink determination will not indicate. In other words, much regarding the washability of a coal can be determined by a laboratory float-and-sink investigation, provided the sample tested is a reliable one. Neither the wet nor the dry process will improve on, in fact will not be as good as, the laboratory test of the float and sink of a particular coal.

J. R. CAMPBELL: Yes. The sink-and-float method is a 100 per cent. job but you can not expect any commercial job to be 100 per cent.

*Engineer, Link-Belt Co., Pittsburgh.

I would like Mr. Arms and others interested in the matter to listen to me in this. What is the washing gravity in a washing job and how do you set it up? There is no such thing as real washing gravity in any coal washer. The gravity is simulated. There is only one true gravity and that is the gravity obtained by solutions heavier than water. Anything else is a simulated gravity. The washing gravity may be defined as that gravity at which by an interchange of sink in the washed coal with float in the refuse, the quality of the washed coal is not impaired; the gravity at which by an interchange of sink left in the washed coal with float left in the refuse the quality of the washed product is not impaired. Efficiently, it will be a job that will leave less than two per cent. sink in the washed coal and not over 3.5 per cent. float in the refuse, depending upon conditions. It is simply a question of mathematics. Washing gravity is directly determined from the washability study that Mr. Affelder mentioned. His company made a very complete job of a washability study on the coal at Jerome. The washing gravity is usually determined by the ash or sulphur or both. If you determine that your ash in the washed coal is six or seven per cent., you look at the gravity curve to see what gravity has to be simulated in the washing job.

R. W. Arms: I am glad to have this subject of washing gravity brought up, especially to help you see that a washing gravity upon which any coal plant operates is a simulated washing gravity. Mr. Campbell represents an organization which has written a great deal concerning washability curves and washing gravity and has set up a fixed standard for those curves which is rapidly becoming the standard used by others as well as his own organization. In a great many parts of the country they had never heard of a washability curve or washing gravity.

In a large percentage of the coal cleaning plants in the United States they do not care about washing gravity or washing formulæ or washability curves. They describe their operation as "cleaning" their coal. It is a more or less crude operation. They remove the slate or sulphur balls and let it go at that. In the far west where coal costs more money, and where the coal itself is a much more complex arrangement of materials than it is in this district, they have to make a more thorough study of the characteristics of the coal and what can be done

by a further removal of material. Coal is not a homogeneous substance. It varies from material which still has ash and sulphur in it and a specific gravity of perhaps 1.2, up to the slates which again still have some carbon in them, with a specific gravity exceeding 2. Between the lightest coal of 1.2 specific gravity, to the heaviest rock exceeding 2, there is a variety of material ranging in ash from the lowest ash in the lightest material to the highest ash of the rock.

There is another misconception regarding the rock in coal. The elementary idea is that slate is 100 per cent. ash. In the various studies that are being made now we find that the ash content of the rock is a very important element. In the Pittsburgh seam the heaviest of the rocks associated directly with the coal have a very low ash content. Some of them sinking at 1.9 or 2, do not have more than 60 or 65 per cent. ash. The rest of it is moisture, or if there is lime associated with it, CO^2 goes off as gas when burning to ash. There is also a small amount of carbon. We have this material which is called by various names—bone coal, carboniferous shale, etc. It becomes the problem of the user and the coal operator to determine what quality will be produced. If you have a product that is two per cent. ash it would be a fine thing to ship and it is conceivable that by further refinements in coal washing system you could wash at 1.25 or 1.30 gravity. The trouble is that you would have on hand the heaviest of your materials, which would then constitute 30 or 40 per cent. of your product. You must either throw it away or provide an intermediate market for this higher ash material, to obtain a relatively small percentage of low-ash coal. That is the problem to-day in coal cleaning, as you go from the simplest devices intended only to remove the heavy material, up to one which fixes as the limit a definite specific gravity. If you decide that you must not lose more than two per cent. of the lighter stuff in the reject, and one or two per cent. the other way, the plant to accomplish that becomes expensive. That definition, however, of washing gravity is a reasonable one. There are times when washing at 1.60 will permit even slate to go in with the clean coal. Why? Because the standard of the trade has established the quality desired and it is the standard of the trade that establishes the washing gravity. If you are in a district that has an average of seven per cent. ash and you have a mine that produces an average of eight per cent. ash, your problem is to do something which

will give you a product to compete with your neighbor. You may be able to do it by a small rejection of material. You will not have any great desire to get ash down below five per cent. unless you can get more money for it. In the last analysis of this coal cleaning problem the probability is that some years hence we shall approach closer and closer to the theoretical washability curve and the limit of specific gravity.

Perhaps some explanation of dual gravity would be in order. This refers to testing the refuse at a low gravity and the coal at a high gravity. The British washeries have been content to use the dual gravity system owing to the fact that in some cases they have to remove a very heavy rock which requires only the simplest kind of a cleaning plant. They test the refuse at a gravity of 1.30 or 1.35 to determine what amount of the lightest coal is lost, and use a gravity of 1.60 or 1.70 on the coal to determine how much of the heavier fractions still remain with the coal. The fact that no attention is paid to the material between these two gravities is unscientific, to say the least. The use of dual gravities for coal cleaning plants must eventually cease, and has practically ceased in the United States.

J. R. Campbell: Mr. Morrow sounded a key-note in coal washing when he proclaimed that research, not "rule of thumb," must be the guiding factor in the future of coal preparation. Moreover, he had the courage of his convictions and proceeded to build a preparation plant around scientific investigations. In other words, Mr. Morrow believes that in the case of science versus luck, science wins every time, all factors being equal.

The "cut and try" method has been eliminated in nearly every important manufacturing process; it must be eliminated in coal washing. The writer confesses to aiding and abetting Mr. Morrow and others who are endeavoring to put coal washing on a higher plane. Captain Jones in the early days of the Edgar Thomson steel-works was wont to say that the chemists and engineers were going to ruin the steel industry. Instead of that, they made it what it is to-day. The same indefatigable workers are rapidly ironing out the kinks in coal washing. It bodes no good for the inefficient washing job to see a "Delatester" and some carbon tetrachlorid on the job with a "blind spot" in each eye to see what is going on. The writer has seen several

such brand-new testing outfits recently which, coupled with efficiency formulæ, will surely get the "low down" on plant performance. Then the heretofore unsuspecting coal operator will realize that a certain class of coal washer was made rather to sell than to clean the coal or recover the good coal lost in the refuse.

The writer in his paper on "Coal Washing; Some Factors in the Problem"* read before the Eastern States Blast Furnace and Coke Oven Association, held in Pittsburgh, June 4, 1927, had this to say:

> "Practical tests do not usually bring out all the facts on the washability of any given coal and often lead to wrong conclusions. We must have the theory to get the practice right."

Again, in his paper on "Cleaning Bituminous Coal"† read before the February 1928 meeting of the American Institute of Mining and Metallurgical Engineers, held in New York, the writer recites substantially the same thing with this addition:

> "therefore he prefers to 'wash on paper' first and then see if the washing equipment measures up to the standard."

In a discussion in 1928,‡ the writer says:

> "In the . . . papers referred to I have shown how washability studies are set-up based on 'sink and floats' data, which is rapidly becoming the universal language both on 'washability' and 'performance.' A few 'rule of thumb' and 'practical test' men still can be found, but they, too, must eventually give way to good theory and its practical application in coal washing."

From his long experience, the writer is convinced that the small practical washing test, as usually conducted, is of doubtful value except as a means for determining the physical characteristics of the resultant product in some manufacturing operation like the by-product coke industry. Even then, the results would not be altogether conclusive. In many cases the time and money are wasted by the small-unit tests and could be spent to far better advantage in intensive research on the washability of the coal in question. This is in line with by-product practice. H. J. Rose of the Koppers Company writes in "Selection of Coals for the Manufacture of Coke":§

*Mining Congress Journal, 1927, v. 13, p. 770-778.
†A. I. M. and M. E. Technical Publication No. 117.
‡Mining Congress Journal, 1928, v. 14, p. 556.
§Trans. A. I. M. and M. E., v. 74, p. 600.

"In the writer's opinion, the most satisfactory method is the distillation of coal in the laboratory, under conditions which duplicate actual coke-oven conditions as far as possible; the by-products are collected, and the yields determined. It is rapid, reliable, and requires but a small sample of coal. Long experience has proved that the success of this empirical test depends upon the rigid control of test conditions by chemists experienced in this work and frequent comparison of laboratory results with actual plant yields for the same coals."

When the writer entered the by-product game this test was known as the "German tube test" which, with established factors, correctly represented by-product practice. At the present time it is common knowledge, we believe, that plant performance and guarantees are based on the dry distillation test in by-product practice. This is an exact parallel with coal washing practice. The washability study of a given coal made by laboratory methods coupled with known factors sets up a standard for plant performance which can not be shaken, because the fundamentals are sound. All these fundamentals are given in detail by the writer in the three papers mentioned.

Let us turn for a moment to hear what eminent technical men abroad have to say on the subject. Prof. Henry Briggs and Prof. Henry Louis read a paper on "The Rhéolaveur Coal-Washer in Belgium,"* from which the following quotations are taken:

"Very complete use is made of washability curves in Belgium, and the engineers in charge of rhéolaveurs understand them thoroughly. They provide at one and the same time an indication of what washing can effect for a particular fuel, and a criterion of efficiency in the actual operation. As the washery-makers' guarantees as to the ash-content in both the washed coal and in the shale discard are based upon these washability curves, the first step in investigating a coal-washing proposal is to obtain the curves for the coal in question. . . . Experience proves the rhéolaveur washer to effect a separation approximating to that indicated by the washability curves; results obtained from the curves are, with that washer, applicable to practice with but little modification."

Mr. E. O. Forster Brown, in discussing the above paper, says:

"This paper sets out very clearly what is being done in Belgium under probably, in the majority of cases, more difficult conditions than those obtaining in this country. I am particularly interested in the subject, because I have recently had to take on the administration of a large number of anthra-

*Transactions of the Institution of Mining Engineers, 1928, v. 74, p. 285-307.

cite collieries where about ten different sizes of coal are made. About half of these, as a rule, are washed. The first thing that I come up against is that there is no specific information on the results I am getting. The lack of organization and scientific control in the majority of washing and screening plants is mentioned in the paper. My own experience may be worse than the average, but such as it is, I quite agree with the authors that we do not organize the scientific control and management of washing as they do in other countries, and that there is a great deal of leeway to be made up in this direction."

Major D. H. Currer Briggs, in further discussion, says:

"This paper draws attention to one very important point, namely, the question of washability curves. I feel certain that our industry in the past has not paid sufficient attention to the scientific side of washing—not so much attention as it should have paid. We have very ample facilities in our universities for finding out what really is the best way of treating our coal, and I think that this paper is bound to do good because it draws attention to this fact. If any company proposes in the future to put up a washer, the first step that should be taken is to go to a university or some scientific institution and find out what is the best way of dealing with their particular coal rather than to select a washer manufacturer to put in a plant selected more or less at haphazard. I should like to ask whether the authors think that at the present time there is any particular type of washer that could deal with all types of coal in this country. I quite definitely believe that it is necessary to examine our coal first and then go to the makers of the particular type of washer to which we are recommended as being the one most suitable for dealing with the class of coal under consideration."

Prof. Henry Briggs, in reply, says:

"We are much obliged for the many kind remarks, and are gratified with the interest the paper has evoked. Of the general questions raised, one of the most important is that mentioned by Mr. E. O. Forster Brown and other speakers, namely, the scientific control of washing plant. Our own system of putting the plant under a foreman, who is left to his own devices so long as no complaints are received, and who is discharged when things go wrong, yields neither the cheapest nor the best results. We have for some time held—and the Belgian visit substantiated our views—that every large washer should be in charge of a properly qualified technologist who can keep a systematic watch on the performance of each machine, who can draw up washability and other curves, and who is able to regulate the washer to accord with changes of market price or to meet the requirements of special purchasers. . . . Major Currer Briggs is quite right: far too little use is made in this country of washability curves; in fact, they are hardly known. Without these curves being obtained beforehand, it is almost impossible to

ascertain what washing will do, or ought to do, for a given coal. They provide the only logical basis on which to judge of the performance of an actual plant or of a maker's promises. As Major Briggs states, a university or technological laboratory can examine the coal first; it can provide, quite inexpensively, washability curves, sizing data, and other particulars, and then the colliery company can approach the various washery makers and find from them how near they can come to realizing the results the examination furnishes, having regard to prime and operating costs, ease and flexibility of control, etc. . . . It seems to us that here is the true function of the laboratories rather than that of deciding which particular plant should be installed."

It so happened that this discussion concerned the "Rhéolaveur" system of washing, hence the references to it at times. What the author is endeavoring to point out is the trend of the times on both sides of the water—the necessity for washability studies of coal and the corollary that follows, plant control. When we get both, and formulate the results, American engineers will step to the head of the class in coal washing. Some of the university men of the country have been good enough to write me that our efforts are not in vain—that our preachment from the housetops is not a "voice crying in the wilderness"; that it is good to see an American attempting some educational work in coal washing, all of which is made possible by the policy of the American company which I represent. We want to do constructive work and not hide our light under a bushel. We ask the co-operation of the coal operators and technical men engaged in the task before all of us—the efficient preparation of the coals of the country on the basis of the economic principles involved and along the lines of pure reasoning—research versus "rule of thumb."

As a standard for chemical analysis, washed coal $= a + 0.5$ per cent., and refuse $= b - 3.5$ per cent., where $a =$ theoretical ash in washed coal, and $b =$ theoretical ash in refuse, in washability study. Sink-and-float sulphur in the washability study may be taken as determined for the practical sulphur. In many cases a factor can be used for the washed-coal sulphur—say 0.9, which seems to be an observed fact.

In the following formulæ, $Q =$ qualitative efficiency, $Q' =$ quantitative efficiency, $W =$ washed-coal float, $F =$ feed-coal float, $R =$ refuse float, $S =$ percentage of sink in feed coal, and $S' =$ percentage of sink in washed coal.

DRAKELEY'S FORMULÆ

$$Q = 100 \times \frac{W - F}{100 - F}$$

$$Q' = 100 \times \frac{F - \frac{(\%\ \text{refuse})\ R}{100}}{F}$$

$$\text{Bank loss} = 100 - Q'$$

DRAKELEY'S FORMULÆ MODIFIED BY CAMPBELL AND WALLE

$$Q = 100 \times \frac{S - (100 - \%\ \text{refuse})\ S'}{S}$$

$$Q' = 100 - \frac{(\%\ \text{refuse})\ \%\ R}{100}$$

$$\text{Bank loss} = 100 - Q'$$

The following is a standard sink-and-float formula:

Not over two per cent. sink in washed coal and not over five per cent. float in refuse (all sizes) at the washing gravity, when there is approximately 10 per cent. sink in raw coal.

PNEUMATIC OR DRY CLEANING OF BITUMINOUS COAL*

By Charles Enzian†

INTRODUCTION

The progress of mechanized mining, and the advancement made in the more scientific utilization of bituminous coal, in its broad sense, and reflected in modern mining practice and in market conditions, forcefully suggest to the bituminous operator that he is confronted with the necessity of either mechanically or physically cleaning or preparing his coal for market. To accomplish this in the most practicable manner he must select a process that will yield a resultant product most closely approaching the physical characteristics and chemical quality demanded by his market. In this he immediately faces the economic as well as the practical limitations imposed by location and the character of the raw product produced by his mine. These, in turn, determine the selection of a process which will yield the essential results in the most economical and practical manner.

RESEARCH WORK

The determination of the physical characteristics of the mine product and the chemical composition of the various components, when the product is studied in detail, is one of the most tedious and difficult elements in the entire problem. The research engineer will immediately discover that if the product is segregated into groups of sizes, a great variation, both in physical characteristics and chemical quality, will be found. For example, he will find that the sizes larger than three or four inches can be efficiently cleaned by hand, while the smaller sizes must be cleaned by mechanical processes. When these smaller sizes are further segregated into components of two or more sizes, a great variation in these will be discovered. The results of the studies of these elements will then determine the method which, in practical operation, will yield the results desired.

FIELD AND LABORATORY STUDY

At first glance this much of the problem appears quite simple, but it does involve, first of all, a very careful and intensive program

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of sampling at the face of the mine workings and on the railroad cars; screen tests of the run-of-mine product; float-and-sink studies; chemical analysis; the intimate characteristics, both physical and chemical, of the impurities to be removed; and the construction of washability curves which will enable him to determine the possibility of attaining, in a mechanical separating process, the laboratory results obtained, especially as to the possible loss in weight, or "rejects," in preparation which forms an important element in the cost of operation.

The next important step is to determine what practical results may reasonably be expected from a commercial plant, by conducting tests in properly equipped testing plants using car-load lots of coal. When the foregoing has been accomplished the results will quite accurately indicate the practical returns from treating the raw product by either one of the two most common and practical processes—hydraulic or pneumatic separation. From the washability curves and the work of the testing plant you determine the effect upon the resultant marketable product of weight loss, gravities of impurities, breakage in handling the raw product incident to the system, the changed physical characteristics of the product due to breakage in screening, tabling, and rehandling the coal.

It may be presumed that the reader is familiar with the details of the field and laboratory studies above mentioned, and therefore no time will be consumed at present in detailed discussion, and the writer will confine himself to the pneumatic process of cleaning bituminous coal.

PNEUMATIC OR DRY CLEANING PROCESS

The pneumatic process, in its present stage of development, consists generally of what may be termed the "composite" and "integral" systems. The composite system thus far developed eliminates practically all prescreening, and this constitutes a highly desirable feature of any cleaning plant for soft and friable coal. It is quite obvious that the successive handling and screening of bituminous coal causes breakage which may be undesirable from the viewpoint of fineness of product, objection to presence of dust, and the incidental added expense of dust collection. In addition, it may be pointed out that it presents attractive features for pneumatic coal cleaning installations

for small-capacity plants. The operating units are larger but fewer in number, resulting in simplicity and ease of installation for part-product cleaning plants. Its application, however, unless retreatment units are installed, may not be found as generally applicable, or as flexible for cleaning a varied raw product as the integral system, such as employed in the two plants—one operating and another in the course of construction—of The Berwind-White Coal Mining Company, near Windber, Pa.

OPERATING PLANT

The one plant, with a capacity of 400 tons an hour, has been in operation for over two years. From preliminary studies in laboratory and testing plant it was found advisable to separate the run-of-mine product into the following integral elements:

Through mesh, inches	Percentage of total
3½ round	2.50—16.50
3½ by 1¾ square	3.75—12.00
1¾ by 1¼ square	4.00— 5.00
1¼ by 13/16 square	4.00— 5.00
13/16 by ½ square	6.00— 7.00
½ by 3/16 square	17.00—18.00
3/16 by 5/32 square	16.00—19.00
5/32 square	27.00—46.00

The relative percentages of these different sizes vary from 2.5 to 46. For the three sizes from 3½ inches to 13/16 inch, comprising about 16 per cent. of the separator product, one table is required for each size. For the sizes smaller than 13/16 inch two tables are required for each integral size. The sizes smaller than 3½ inches, round mesh, comprise between 83.5 and 97.5 per cent. of the total run-of-mine output. The coal larger than 3½ inches is hand picked on the upper section of the main shaking screen in the tipple section of the plant and discharged into a chute where it is mixed with the clean 3½-inch product from the separator, and then discharged into the railroad cars as run-of-mine product. In a representative test, the ash reduction by hand picking in the tipple amounted to four

per cent. as compared with a total reduction of 40 per cent. in the entire product cleaned in the separator and tipple.

The separator is a three-floor structure built into the tipple and consists of a space 36 feet wide, 110 feet long, and approximately 60 feet high. The ground floor is occupied by table fans, the middle floor by concentrator tables, and the third floor by screens. The fans, tables and screens are arranged in two parallel rows lengthwise along each side of the separator building. There are 60 motors, aggregating 1031½ connected motor horse-power, 83 per cent. of which is required to operate the separator. The power consumption for the entire plant operation and lighting averages 1.76 kilowatt-hours per ton cleaned. The cleaning plant is equipped with fire protection, steam heat, and a vacuum cleaning system. It is also equipped with complete sampling and float-and-sink equipment, a foreman's office, and a storeroom for supplies and extra repair parts.

The total cost of the plant was approximately $940 per ton-hour capacity. The grading of the site and relocation of tracks amounted to about seven per cent. of this cost. The operation of this plant adds approximately six per cent. to the previous mine costs, equally divided between operating and capital charges. This additional expense is, we feel, entirely justified by the improvement in the shipped product. The mine product is of variable quality, but the quality of the cleaned coal is practically uniform. The ash reduction varies from 15 to 60 per cent, depending on the character of the input. This wide range of variation in ash reduction is due to the difference in quality of hand loaded coal and mechanically loaded coal. The plant under discussion was, up to several months ago, treating a mine product in which 25 per cent. was mechanically loaded coal, which, as is generally recognized, contains a higher and more variable amount of impurities. The average ash reduction by the plant is consistently about 20 per cent. Sulphur in ash reduction has varied from 25 to 40 per cent., depending on the character of the input. The consistent average sulphur reduction is about 35 per cent.

The amount of "rejects," or hand picked and separator refuse, on a weight-loss basis, varies from four to six per cent., with a consistent average of five per cent. If mechanical loading were eliminated, the "rejects" would probably not exceed four per cent. The ash content of the "rejects" is also variable, but a consistent average

of 35 per cent. has been realized. The sulphur content in the refuse varies also, but averages about 13 per cent. The great variation of the ash and sulphur content of the "rejects" is directly proportional to the character of the impurities removed from the run-of-mine product. These impurities consist of:

	Ash content, per cent.
Iron pyrites	59.0
Shale	74.0
Fire-clay	74.0
Bone	40.5
Weighted composite	48.2

The specific gravities of these materials vary from 1.45 with 14 per cent. of ash, to 1.9 with 74 per cent. ash; the sulphur content in these refuse constituents varying from 2½ to 35 per cent.

NEW PLANT

The new plant, now under construction, is a concrete-steel structure, and it also has a capacity of 400 tons per hour. The tipple portion has been in actual operation since September 1, 1928. In it a dual system of coal cleaning is being installed. The sizes larger than four inches, round mesh, are hand picked on a Marcus screen; the size 4 by 1½ inches, which represents about 16 per cent. of the total separator product, will be cleaned in a Menzie "hydro" separator, and the sizes 1½ inches and under will be pneumatically, or air cleaned with 12 Arms air-concentrator tables, as follows:

One table for the 1½- by 13/16-inch size.
One table for the 13/16- by ⅝-inch size.
Two tables for the ⅝- by 5/16-inch size.
Four tables for the 5/16- by 5/32-inch size.
Four tables for the 5/32-inch size.

The introduction of the "hydro" in the new plant is in line with two years of operating experience with air tables, and comparative results obtained in the testing plant with the "hydro" separator. The experience, in the present operating plant, with the 3½ by 1¾-inch size cleaning on the Arms air table (which we understand was the

largest size with which air cleaning has been attempted) yielded a product fairly satisfactory, but not as uniform in quality as is desirable. From tests conducted in the Roberts and Schaefer Company's testing plant at Harvey, Ill., we have every reason to believe that the Menzie "hydro" separator is more efficient on this larger-size product than the pneumatic process has proved to be.

It is to be borne in mind that our coal is very friable. The percentages of relative sizes previously mentioned indicate that more than 70 per cent. is smaller than ½ inch, square mesh. This physical condition of the product and the severe winter conditions of our region, definitely limit us to dry preparation. It is estimated that the "hydro" treatment of coal 4 by 1½ inches in size will increase the moisture content of the plant product about one-half of one per cent., which is just about the practicable limit of moisture we have set for our plant product.

The ash reduction of the entire mine output is expected to be 20 per cent, and the sulphur reduction about 31 per cent. The separator "rejects," or mine weight loss, may be estimated at 4.5 per cent. of the total plant input. This refuse is expected to analyze 29.4 per cent. ash, and 11.8 per cent. sulphur. The hand-picked refuse will probably not exceed 0.1 per cent of the total mine input, or only about two per cent. of the total refuse removed, and therefore only 1/49 of the quantity of refuse removed by the separator. Tests indicate that the hand-picked refuse should analyze 21.1 per cent. ash and five per cent. sulphur.

This plant has 79 motors, aggregating a total connected horsepower of 769.25, about 88 per cent. of which is required for separator operation.

The loading and mixing facilities in the new plant are practically duplicates of the present operating plant. The shipped product may consist of run-of-mine, lump, egg and stove, stoker or combinations of any or all of the above sizes.

The total cost of the new plant, inclusive of the Pangborn dust-collecting system, is about $1003 per ton hour capacity. Ninety per cent. of this cost is for grading of the site, foundations, and construction and equipment of plant proper, and 10 per cent. of the total cost is represented by track changes, power-station and lines, heating system, etc.

The loaded and empty mine-car traffic, weighing the coal, and dumping the cars will be handled by four men. The entire plant will be operated by two men less than required on the old tipple displaced by the new plant. The principal accomplishments expected of the new plant may be summarized as follows:

1. Smaller operating personnel than old tipple.
2. Fire-proof and steam-heated modern tipple and cleaning units.
3. Uniform quality of resultant dry product.
4. Elimination of dust inside and outside of plant.
5. Reduction of ash and sulphur content of resultant shipped product amounting to 20 per cent. and 31 per cent., respectively.
6. Preparation rejects and plant loss amounting to about 4.6 per cent. by weight.
7. Probable composition of refuse, 29.4 per cent. ash and 11.8 per cent. sulphur.

From information furnished by the American Coal Cleaning Corporation, Roberts and Schaefer Company, Heyl and Patterson Company, and Pennsylvania Mining Machinery Corporation, it appears that 35 bituminous coal companies in the United States and three companies in Canada now have dry coal cleaning plants in operation and under construction, or in process of design. Four of the above plants in the United States employ the "hydro" separator for the larger or top sizes.

The writer gratefully acknowledges co-operation in the collection of information by the four manufacturing and contracting companies above mentioned, and also acknowledges the use of plant records of operating companies.

DISCUSSION

R. H. Schaller:* How does the efficiency of the dry cleaning plant decrease with increased moisture in the coal?

Charles Enzian: First of all you do not have the efficient size that is highly desirable. Second, you have the increased specific gravity

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of your product which will of course tend to go over at the refuse end and in the middlings. I think those are the two principal effects.

E. A. HOLBROOK:* I would like to ask how you determine when to stop hand picking and when to commence cleaning by machine. In other words, how do you determine at what size hand picking will no longer pay?

CHARLES ENZIAN: It is better to clean down rather than clean upwards. Of course it could be worked in the reverse order. As an example I can state the results of a test. We took a portion of a railroad car of the larger sizes and hand picked it. Half of it was hand picked, removing the refuse to the extent we thought practicable. It took something like 16 man-hours to accomplish that. The air tables cleaned the same size and quantity to almost the same degree of quality in two hours. It shows that it is a physical impossibility to clean the small-size coal by hand. At the mine where we have been operating the air cleaning plant over two years, it would be physically impossible; but in some of our other mines the quantity of refuse in that size is so small that probably four men might pick it by hand; though even then you would have four men as compared with one table, and in our worst product it would probably take more men to do the work that one air table or "hydro" separator would perform.

T. G. ESTEP:† What effect does this cleaning have on the fusing temperature of the ash? In your hand picking, not using any mechanical cleaning at all, how much do you reduce the ash content, on the average?

CHARLES ENZIAN: To answer the first question first, it increases the ash-softening temperature about 200 degrees as an average. The hand-picked refuse, on the average, I think I stated, was from two to four per cent. That required four men. Keep in mind that that is a size of refuse that can easily be discerned by eye and handled readily by the hand. On this particular test, two per cent. was hand-

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picked refuse that was above four inches in size and 98 per cent. was smaller than four inches. As I stated in the paper, in our No. 37 plant, which has been in operation over two years, we have four tables on the sizes smaller than 5/32 inch. It should be borne in mind that the air separator removes refuse which would be physically impossible to remove by hand.

J. R. Campbell:* There is just one thing about this question of conversion cost that Mr. Enzian speaks of and which is a part of the cost just as surely as the operating cost. This was brought to my attention by a mining engineer sometime ago. If we have a 1000-ton washing job and lose 10 per cent. in washing, and if you have a mining cost of $1.50 a ton, the conversion cost will be 15 cents a ton, in round numbers. This engineer called my attention to the fact that if you are shipping 1000 tons a day of raw coal and want to ship 1000 tons of washed coal, you would have to mine approximately 1100 tons, or 100 tons more coal, and this extra 100 tons would not carry all the usual charges. You could safely figure out 2/3 of the cost. He called my attention to the fact that this ought to be credited to the conversion cost and in some cases it would amount to four or five cents a ton. If you have a coal cost of $1.50 and the extra 100 tons cost only $1, you have 50 cents to the good which may be credited to the conversion charge.

R. W. Arms:† There are several ways of looking at this matter of conversion costs. A unique way came to my knowledge in western Canada where they are mining a vertical seam. They do not make any charge to the cleaning plant for the refuse losses but credit the mine with clean coal only. Originally it was only hand picked. They then installed some dry cleaning apparatus, but they credited the mine with only the coal loaded out on the railroad. Naturally you would expect the mining cost to go up because they constantly decreased the credit of cleaned coal. Actually it did go up temporarily, but as the cleaning plant became more efficient they were able to inaugurate economies in underground mining and bring out more and more of their non-commercial coal, recovering the good coal from it in the cleaning plant and by that means decreasing the cost of underground

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mining. Ordinarily in this country that is not so simple. I mean to say that only in rare cases can we exercise any economies underground, by less expensive mining operation, because of having a cleaning plant on the top. As a matter of fact I am a firm believer in the principle of getting the coal as clean as possible underground. The proper way to clean coal is to mine it clean regardless of whether you have a cleaning plant or not. The savings you can make in the mining cost by being careless, or using some cheaper method of mining, are usually not really profitable, because of the cost of handling the extra material between the working face and the cleaning plant.

There are a good many innovations in the design of this No. 40 cleaning plant which we are not yet ready to say much about, but they will be apparent to all when the plant is completed. One of the criticisms of air cleaning has always been the handling of the dust. Naturally when an air plant is installed it is dirty. The mere fact that you are working a dry coal and blowing it about with air is the ideal combination of circumstances to create dust. The removal of dusty air from a cleaning plant is comparatively simple. You need only apply a sufficient volume of air to withdraw the dusty air from the plant. That withdrawal must start with the entire volume of air that is used to clean the coal, and it must have roughly a surplus of 25 per cent. in order to make sure that leakages in the dust-collecting system are included. On the recovery end an entirely different problem presents itself. The expense of recovery depends not on the amount of dust in the air but on the volume of air. If you are rather prodigal in the amount of air used in collecting the dust you reap your reward in trying to get the dust out of it. At the original No. 37 plant we were forced to handle in the neighborhood of 180,000 cubic feet of air a minute to accomplish the cleaning. That is more air than an ordinary sized coal-mine requires for its entire ventilation. That air passes through the plant at a high velocity under rather high water-gage and sometimes with tremendous friction losses. It requires a lot of power and considerable expense for the removal of the dust from this volume. In designing a plant that would more adequately remove the dust from the air, our problem was to reduce the volume of the air that had to be handled finally in the dust-collecting apparatus. If that volume could be reduced far enough, we could afford to put in a high class of collecting equipment. By a system of recirculation

of air within the plant we not only succeeded in reducing the volume of air handled but have reduced the number of motors by coupling up the tables in groups of three or four. By this system of recirculation we have reduced the amount of air required for dust collecting from 180,000 cubic feet to approximately 55,000 cubic feet per minute. The loading of the dust increased from one or two grains per cubic foot up to perhaps twenty grains per cubic foot, but with a much reduced volume of air. With that reduced volume we were able to put in an automatic arrester to remove the dust from this air. This arrester is nothing new. It has been used in many thousands of installations on other materials, some associated with coal, as in the foundry business. This system depends on the principle of shutting off one-eighth of the system at a time, shaking it free from dust, and throwing it back into operation. This is done automatically by electric contacts and time-delay switches. By that means there is always a constant back-pressure and a constant volume of air being removed from the cleaning plant at all times.

Thomas Fraser:* It seems to me that Mr. Campbell's suggestion that the washing plant be credited with the saving in overhead cost per ton of coal mined, due to the increased tonnage that must be mined to maintain the previous rate of production of shipped coal, really introduces a much larger item that may be relied upon to make the operation of the cleaning plant profitable even when the balance-sheet does not show a profit credited to the plant. This item is the saving in general mine operating costs per unit of production made possible by larger production and steadier operation which, in turn, are made possible by the stronger competitive position of the coal marketed from the cleaning plant. While the new tonnage that must be mined to maintain the former rate of production is a comparatively small item, the enlarged production that may be brought about by an improved product holds out great possibilities of overall cost lowering. This condition must usually be taken into consideration to justify the investment in a cleaning plant. While some specially prepared coal has doubtless been sold at a premium, this is by no means to be depended upon, and, where a higher selling price is actually realized, this is a minor item compared with the general sales value of the plant.

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C. E. LESHER:* I do not think the factor of increased tonnage can be figured in in any shape, manner, or form. I just register that as my opinion, without going into details. That is an old fallacy in the coal business and one of the foundations for the low market price we have for coal to-day. It hasn't anything to do with cleaning. Whether you have a cleaning plant or not, do not fool yourself that way.

I also wish to register exception to the statement that you can not justify a cleaning plant commercially. That is rather a broad statement. Our experience, in the Pittsburgh Coal Company, with an entirely commercial cleaning plant, is quite to the contrary. We have justified it. After some time merchandizing that kind of coal we have reached the point where it does pay for itself. We have to take into account that conversion factor, and we have found that the clean coal can be sold and you can recover your money out of it.

THOMAS FRASER: I take it that you can get more for your cleaned coal. In some cleaning plant jobs with which I am familiar, operators have been disappointed in their expectations of obtaining a premium on their washed coal, but the plants are still being operated. This is by no means a pessimistic attitude on coal washing. It is just taking the position that the object of washery operation is to meet competition and broaden markets by improving the product. That it is not unsound business policy to do this even when the cost can not be passed on to the consumer is evidenced by the fact that it is being done in many other industries that operate more profitably, as a rule, than the bituminous coal industry. In fact, in many profitable enterprises, large sums have been spent over a period of years to improve the product while at the same time unit selling prices were being lowered, much to the ultimate advantage of the stock-holders.

W. L. AFFELDER:† I can not quite understand—if Mr. Lesher can get more for his cleaned product, inasmuch as it is a premium product—why he can not produce and sell more of it in competition with an inferior product.

*Executive Vice-President, Pittsburgh Coal Co., Pittsburgh.
†Assistant to President, Hillman Coal & Coke Co., Pittsburgh.

C. E. LESHER: No. I said it was a fallacy to say that that additional tonnage of 100 tons (to take Mr. Campbell's example) at a decreased cost is a credit to the cleaning department. It is a credit to the mining operation, if you want to do your bookkeeping that way. Whether you clean it or not you get the same increment of cost.

W. L. AFFELDER: On the other hand, Mr. Fraser's point was that if, by cleaning, you can create additional markets and sell more coal, your production cost will be lower per ton.

C. E. LESHER: He did not say that.

W. L. AFFELDER: I understood him so. He said it might be that the extra 100 tons necessary to make up what was lost in the cleaning process might favorably influence the average cost, but he also said that on account of the superiority of the product it was quite likely that the total production of the mine might be considerably increased and thereby help the cost in other ways.

C. E. LESHER: There can not be any argument about that. You have a cleaning plant and make it pay and you can get more out of it; there is no argument to that.

W. L. AFFELDER: By that increased production you can offset to a considerable extent the cleaning cost, provided the additional tonnage would not have been salable without cleaning.

J. R. CAMPBELL: I think you are both right.

C. E. LESHER: You might manage 1000 tons product and you could not get the other 100 tons. Then you have to take it off.

P. NICHOLLS:* I missed the earlier part of the discussion but I believe it would be pertinent to refer to the effect of cleaning on the clinkering characteristics of a coal. There is little definite information available on the relative advantage to a user of a cleaned coal. The gains because of a reduced *quantity* of ash, in increasing the

*Supervising Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

calorific value per pound, in saving in the freight charge, and in reducing the quantity of ash and clinker to be handled, are obvious and can be translated into dollar values. There is less certainty as to whether the cleaning will give a better fuel because of an improvement in the *quality* of the ash. Such improvement would be evidenced by a less troublesome clinker, or by a relatively smaller proportion of large clinker in a given weight of fuel-bed refuse. It might also show up in improved burning characteristics.

At the Pittsburgh Experiment Station of the United States Bureau of Mines we have been studying the clinker formations resulting from the burning of coals in an experimental furnace simulating the hand-fired, or overfeed, method. The main objective of the investigation was to compare the clinkering characteristics with the properties of the coal ash, and in particular, with its fusion temperatures.

As part of this investigation we received for two coals samples taken both before and after cleaning. Some of the more pertinent facts regarding these coals and of the results of the tests are given in the following table:

	Bituminous Pennsylvania		Semi-bituminous Pennsylvania	
	Uncleaned	Cleaned	Uncleaned	Cleaned
Ash, per cent	11.0	8.2	9.2	7.9
Total sulphur, per cent. in coal	1.52	1.63	1.93	1.47
Pyritic sulphur, per cent. in coal	0.73	0.64	1.42	1.02
Fe_2O_3, per cent. in ash	10.9	12.9	24.2	19.3
Ash-softening temperature in degrees F	2600	2570	2470	2630
Ash fluid temperature in degrees F	2700	2700	2560	2720
Residue as clinker over 2 inches, per cent	32	17	30	10
Residue as clinker over ½ inch, per cent	66	48	53	33

The last two lines of the table give the quantity of clinker over a given size, expressed as a percentage of the total ash residue; they are therefore qualitative measures of the clinkering tendencies of the coals. It will be noted that both cleaned coals show improvement; that is, a decrease in quantity of large clinker. The bituminous coal benefited mainly by the removal of extraneous material with a comparatively small gain by the removal of pyritic iron; the fusion tem-

peratures of the average ash were not changed by the cleaning. The semi-bituminous lost only 1.3 per cent. ash by the cleaning, but this was mainly pyritic iron; as a consequence its ash-fusion temperatures were raised 160 degrees.

These results show that cleaning coals can produce an improvement in quality in addition to that due solely to the reduction of the quantity of ash. It should not be expected, however, that the improvement would usually be as large as that shown by these special burning tests. If, for example, the coals were burned by the underfeed method, the ash would be subjected to the high temperatures for a longer time, and the whole of the ash remaining in the fuel-bed would tend to be slagged, independent of slight differences in its quality.

We have recently carried out a series of tests on a moderate-size power boiler, in which we measured clinker formation and observed troubles due to clinkering when burning different coals. The results are not available for publication at this time, but they show that for the similar types of coals tested, the troubles attributable to clinkering decreased as the fusion temperature of the average ash of the coal increased. Such tests require very close observations to obtain results which can be given numerical values. It is suggested, however, that it is very desirable for those interested in the cleaning of coals to have more definite data on improvements in the utilization attributable to the cleaning.

W. L. Affelder: Mr. Enzian, in comparing his No. 40 plant with No. 37, indicated a very large reduction in connected horse-power in the former. In the one case, it was over 1000 horse-power to 400 tons an hour, and in the other case it was only 700. Mr. Arms may be able to state whether the reduction was due to the change in the air circulation or in the dust-collecting system?

R. W. Arms: The reduction of horse-power was very largely due to the use of the recirculating method of handling the air and the dust at the same time. We have two uses for air. One is as the primary separating agent and after it passes through the tables it becomes dust laden and passes into the realm of the dust-collecting department. In the old plant we have an individual motor on the fan for each table. After the air leaves these tables there is an abrupt

break. The velocity is reduced and it passes from the table into the dust hood where the dust-collecting fans must start all over again and pick that air up from practically a state of rest and pass it into the dust-collecting system. The power involved in dust collecting alone in the old plant was about 300 to 350 horse-power. In the new plant we have coupled up the primary movers of the air with secondary dust-collecting movers, using those fans for recirculating air; that is, we use some air that was formerly passed directly to the dust-collecting system as a recirculating medium—dust laden, to be sure, but more effective as a separating medium because of a slight increase in specific gravity due to the burden of dust. We start with a series of four tables, each with its own size of coal. Starting at the smaller end which has the smallest air requirement, we use the dust-laden air from the hood as the cleaning medium for the second table. So on down to the end. The only air which needs to go to the dust-collecting system is the air from the last table plus its 20 or 30 per cent. surplus necessary for leakage through the hood. In each case we have passed air from one table to another until the final requirement for the dust-collecting system is the air of the last table. By using this system, we were able to eliminate nearly 30 per cent. of the horse-power.

F. A. Jordan:* The thing that impresses me with this matter is the great progress made in the short period of two years. I think Mr. Enzian will admit that the first day he ran his first plant he was somewhat disappointed. I can not help but notice the great progress they have made in that particular process, and it rather points out to me that we have a long way to go yet before we get through perfecting this problem of coal cleaning.

I would like to commend Mr. Enzian in the general features of his paper. It is worthy of a good deal of study on the part of those who want to compare their problems with his. I particularly have in mind the fact that he does not set any very definite lines for performance, because it can not be done. It simply means that the character of the product which comes to his plant varies from day to day, and I think the paper presented has been a very fine presentation of the problem.

*Youngstown Sheet & Tube Co., Youngstown, Ohio.

L. O. Lougee, *Chairman*:* Mr. Crawhall, can you tell us anything of the progress of this work in England?

J. S. Crawhall:† I am afraid I can add little to the discussion, as my experience in Great Britain was mainly confined to shaft sinking and dealing with water problems in mines. I think, however, that the United States has done more pioneer work in the dry separation of coal, due to the relatively higher transportation costs over long hauls and the greater difficulties experienced from having coal frozen in the cars. British coal owners, however, appreciate the merits of dry cleaning, and are keeping a watchful eye on developments on this side.

Roughly, I would say that about 80 per cent. of the coal which is washed in Britain is dealt with in Baum plants, but the easier operation of the Rhéolaveur system makes a strong appeal, and the latter type appears to be rapidly on the increase.

W. L. Affelder: I should like to suggest a discussion of an allied subject that has a very important bearing on this question of coal cleaning, whether wet or dry, but especially dry cleaning. That is the question of proper screening of the coal before attempting to clean it. What is the better way to screen coal—to take the coarse sizes out first and go on down, or start with the fine sizes and go on up? There is quite a difference of opinion on that question.

R. W. Arms: Several years ago a question arose as to the best way of doing it. In early screen practice, first came the bar screen which made one separation, and following that, the shaker screen made three or four sizes. Now, in air cleaning plants as many as seven or eight sizes are made, and screening methods become a problem. In a large measure it depends on the type of equipment you are using. In our particular case we designed our equipment to reverse our former practice. We used to use a type of gravity screen—one of the best vibrating screens on the market—but being set at a 30-degree slope to make a succession of sizes we were forced by the head-room required to take out the small sizes first. In other words, the

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feed on the first screen passed its oversize material directly on to the next screen, from which a little larger size was taken. You will easily see that in order to reverse the system you would have to take off these top sizes as a finished product, and pick up the bottom size for the second screen, which requires considerable head-room.

When we designed the type of screen we are now using we put the coal on the biggest screen first for the reason that a large screen has a larger capacity per square foot than a small one and you remove a certain amount of the feed as a finished product at once, so that the feed for the second screen is reduced in tonnage. Furthermore, you remove from the system as soon as possible the larger sizes of coal which are subject to a greater percentage of breakage. Nut-coal and pea-coal are more susceptible to breakage and degradation than the finer sizes. The sooner you can remove them from the screening system the sooner you will be free from breakage trouble. I do not know whether the opponents of that line of thought are represented here, but we might as well give the argument for both sides. Screening the small coal first always lends itself to a simpler system. Your big size is in a more convenient position to be taken away and the oversize passes directly to another screening surface regardless of whether that surface is horizontal or a steeply sloping surface. This controversy is not exactly confined to small sizes. It is proper also on lump, egg, and the larger sizes of coal to remove small coal first. As it happens, the organization for which I work not only has a horizontal screen for fine coal but also one for coarse coal. We found many years ago that the same thing held true, that lump coal should be removed first on the top deck and the fine sizes of coal serve as a cushion for the coal that passes through the holes and if there are several sizes to be made the slack is always protecting from breakage the size that is passing through the screen plate. We feel that the question is settled. We feel very positive that on any screening system, large or small, where several sizes are involved, the large material should be removed first.

Charles Enzian: With our extremely friable coal, the system he describes is the most practicable. The larger sizes traveling over successive screens would tend to break down to a still greater extent into smaller particles. We have to clear our large sizes first.

J. R. CAMPBELL: I really have nothing to say on this. It is a very difficult problem to screen dry on the fine sizes, and it is easier to screen wet afterwards if you have to make sizes. Our job does not encounter that problem. We wash coal from five inches down, with no prescreening. Prescreening is as essential in most of the wet washing jobs, as it is in most of the dry-table jobs.

L. O. LOUGEE, *Chairman*: Mr. Jarvis, can you add anything to the discussion?

F. W. JARVIS:* No, except to say that in a recent test, the Peale-Davis cleaner operated very satisfactorily, cleaning coal seven inches and under without previous sizing.

R. H. SCHALLER: I should like to ask Mr. Jarvis what effect moisture has on the working of his table.

F. W. JARVIS: I do not believe I am capable of answering that question.

E. G. HILL:† What is the effect of uneven loading on the table?

CHARLES ENZIAN: Uneven loading of the table, of course, impairs the efficiency. It is like any other machine, the more uniform the loading the better the performance. We very rarely find any difficulty in that respect. If we have an excessively fine product going on to our tables we find that the separation in the more uniform loading is better than with intermittent loading.

*Special Agent, Peale-Davis Co., Pittsburgh.
†Associate Professor of Metallurgy, University of Pittsburgh, Pittsburgh.

PURCHASING PUBLIC UTILITY POWER FOR INDUSTRIAL USE*

By W. B. Skinkle†

An ever increasing number of the industries of this country are becoming customers of, and are depending on, the various public utility power companies for their main, and often sole, source of primary power. In view of the industrial importance of the matter and the vigorous and widespread propaganda both pro and con, it seems advisable to examine this subject, analyze some schedules under which electric power is purchased, and investigate the economics of the situation, perticularly from the standpoint of the purchaser of electric energy.

There are few industrial undertakings which are generally as thoroughly misunderstood, and often as greatly abused as the purchase of electric energy from a public utility company. Most purchasers, including managers, operators—and very often engineers—seem to regard a public utility transmission and distribution system as some sort of a miraculous pitcher from which an inexhaustible supply of electric energy pours forth at any desired rate of flow. These same people are often the first to yell "Robber" when the bill for power comes in at the end of the month. They fail to realize that during a period of indiscriminate use of electric power, they may create an unnecessarily high demand and small load-factor which results in a disproportionately high cost of the energy.

The problem of designing or setting up a rate schedule under which electric power can be sold to consumers who have an almost infinite variety of ways of using the energy, is a very difficult one, if any attempt is made to distribute equitably the costs of the service according to the character of use of the energy.

The solution of this problem has resulted in a variety of so-called rates, which, to the average consumer appears to be a mass of

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†Engineer, Pittsburgh District Power Committee, Subsidiary Companies of U. S. Steel Corporation, Pittsburgh.

verbal camouflage, assembled in language carefully calculated to convey the least possible meaning to the ordinary casual reader, and surrounded by an endless variety of safeguards that constantly remind him of a new variation of that old boyhood game of "heads I win, tails you lose." After some ten years of careful study of this subject, the author has reached the conclusion that such impressions are the result of lack of knowledge of the subject, and that the average public utility rate schedule is close to a masterpiece of equitable distribution of the costs and profits of one of our most valuable "resources" which *does* meet the exacting requirements of the service and offers electric energy at a low price to the careful purchaser, and at a somewhat higher price to the careless or indiscriminate buyer.

Practically all rate schedules are subject to mathematical analysis and can, within certain limits, be expressed in the form of an algebraic equation. Furthermore, these equations can be expressed graphically, and an interpretation of the result conveys a large amount of information which can be gained in almost no other way. The original conception of this type of graph is the work of Mr. F. M. Van Deventer,* with whom the author had the honor to be closely associated for a number of years. Articles were published in 1921,† graphically presenting the schedules of several utility companies in effect at that time. These schedules have since been lowered, but the principles set forth still hold. Public utility schedules for the sale of large quantities of power usually contain a demand charge to which is added an energy charge. The energy charge is divided into several "blocks" with decreasing rates for each block of increased use of the energy. The algebraic expression of the rate introduces a third quantity which is a "constant" charge. The general form of an equation for any rate schedule is A times the demand in kilowatts, plus B times the energy in kilowatt-hours, plus some constant charge, where A and B are definite numerical quantities.

The technical and mathematical development of these equations is often a long and rather tedious task and will, therefore, be avoided during the presentation of this paper.

After arriving at the proper equations, the construction of the

*H. L. Doherty & Co., New York.

†Analysis of wholesale electric costs, by F. M. Van Deventer. *Blast Furnace and Steel Plant,* 1921, v. 9, p. 374-376, 438-441, 529-535.

graphs is comparatively simple. Graphs of three different power schedules will be presented and discussed. The various schedules will be called A, B and C, and they are fairly representative of the types of schedules under which power is purchased in this section of the country.

Fig. 1 is a graph of Schedule A. In this figure, the net cost of energy in dollars per month is plotted as the vertical ordinate, while the number of kilowatt-hours of energy consumed each month is used as the horizontal ordinate. The group of curves shown in the body of the figure represents the cost of a given quantity of energy when a given demand is created. By following any single line from its origin on the left-hand side, the cost of energy in increasing quantities for that particular demand can be seen.

Before continuing too far with this subject, it may be well to stop and define the term known as "demand" and consider some of the factors which govern and control it. The demand is the rate at which energy is used, or it might be said that it is a measure of the generating and transmitting capacity which the utility company must set aside for the purpose of serving a given customer.

In the three schedules which we will consider, it is the maximum rate at which energy is used in a period of 15 consecutive minutes during the month in question.

In most schedules, there are two kinds of demands and they may radically affect the bill. The first is the measured demand, which, as the term implies, is the demand as measured by the demand meters on the customer's switchboard. The second is the billing demand, which may be the same as that measured, or it may be radically different, depending on the schedule and the manner in which the energy is used or misused, as the case may be.

The demands expressed in the formulæ in the various figures shown will be billing demands. It will be shown later what the differences are between the measured and billing demands and their causes and penalties.

The values shown in the following figures do not necessarily represent the lowest cost obtainable by a consumer under any of the various schedules, as there are many special conditions which can not be shown on a general graph but which very materially affect the

actual bill rendered. Power factor, high-tension discounts for ownership of substations, voltage regulation, instantaneous peaks, off-peak use of energy, etc., offer a variety of special conditions that make it exceedingly difficult to compare rates between power companies unless all the special and local conditions of each and every specific installation are considered. Furthermore, each power company has a number of rate schedules in order better to meet specific conditions of various classes of customers. The rates shown on the accompanying charts are what are known as general power rates. The use of power rates other than those shown might give more favorable costs where the conditions applicable to that particular rate can be met by the customer.

Returning now to Fig. 1, we will note some of the things which are brought out by a graphic study of the contract. A bill has been plotted on this chart showing a billing demand of 5000 kilowatts, when 1,300,000 kilowatt-hours of energy are used. Starting at A at 1,300,000 kilowatt-hours on the base line, move vertically upward until the 5000-kilowatt billing demand line is intersected at B, then horizontally to the left margin where the bill is seen to be approximately $17,380 for the month as shown at C. By following the diagonal lines which radiate from B, we see that the *average* cost of energy is 1.34 cents per kilowatt-hour as shown at D and the load-factor is 36 per cent. as shown at E. Another very interesting feature brought out by this graph is that the customer really paid not only approximately $12,300 for the power he used as shown at F, but the difference between $17,380 and $12,300, amounting to $5080 a month, which the customer is penalizing himself for his own variation from the *perfect* use of the energy consumed.

It would be well to explain right here that the perfect use of electric energy by any consumer is almost, if not quite, impossible, as it represents a consumption of energy at an absolutely uniform rate for 24 hours a day and 30 days of the month. Saving the entire $5080 penalty is, therefore, not a practical or commercial possibility, but it offers a goal towards which we should strive. Later in the paper, some remarkable results achieved by these efforts (and, incidentally, by the aid of mechanical load-controlling devices) will be shown.

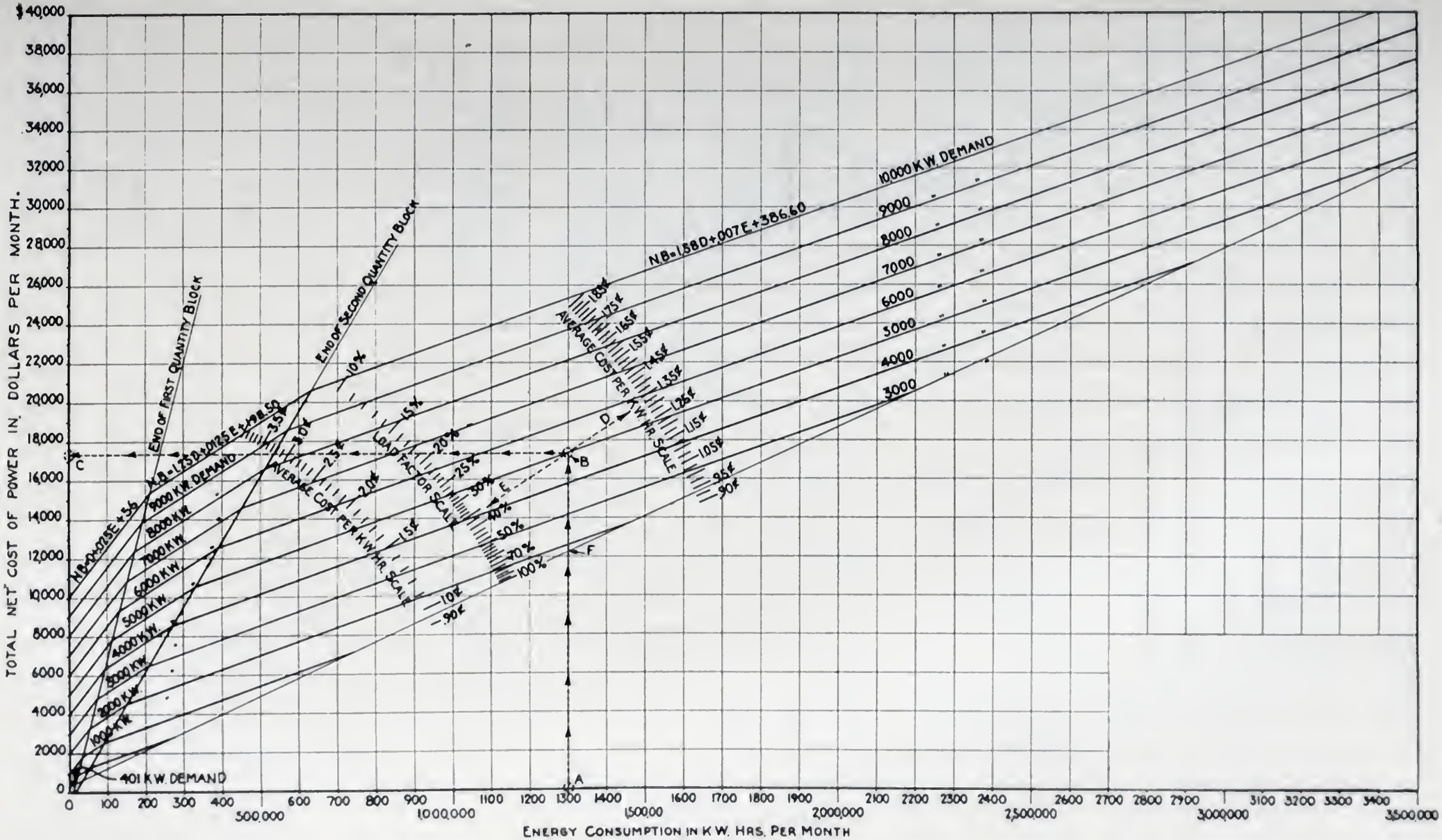

Fig. 1. Graphic Determination of Wholesale Power Costs, Schedule A.

Fig. 2 shows a graphic analysis of Schedule B and similarly we see that the purchase of 1,300,000 kilowatt-hours of energy at a billing demand of 5000 kilovolt-amperes would cost $16,600 a month, or approximately 1.29 cents per kilowatt-hour. In this case, the penalty for deviation from the perfect use of power amounts to $7000 a month and offers quite an incentive to watch the purchases of power very carefully.

Fig. 3 shows a graphic analysis of Schedule C and again we note that the purchase of 1,300,000 kilowatt-hours of energy on a billing demand of 5000 kilowatts costs very close to $15,000 a month, or 1.15 cents per kilowatt-hour. In this case, the penalty for deviation from the perfect use of power amounts to approximately $5800 a month.

Having seen the extent to which penalties accumulate through deviation from the perfect purchase of energy, it will be well to examine into the matter and see what might be done towards avoiding as large a proportion of these penalties as possible, remembering always that from any reasonable commercial standpoint the perfect purchase of power is practically impossible. Under the conditions chosen, bills under the three schedules are analyzed in Table I. A glance at the formulæ in column 7 shows at once that no attempts to change the billing demand or the energy charge will affect the constant forming the last item in the equations.

The second thought that occurs is that the energy represents work done, or product produced, and since the profits of any business are dependent upon the sales of its product, it is at once apparent that no profit would result from any attempt to cut the energy consumption at the expense of actual production.

The only item left for study is the demand, and particularly the billing demand, which represents a very considerable portion of the total bill—actually the billing-demand charge represents between 45 and 65 per cent. of the entire power bill.

To deviate from the billing demand for the moment and go back to the measured demand, you will recall that this measured demand is the rate at which energy is used, or it is a measure of the generating and transmitting capacity which the utility company must set aside for the use of a customer. The demand is measured by a demand

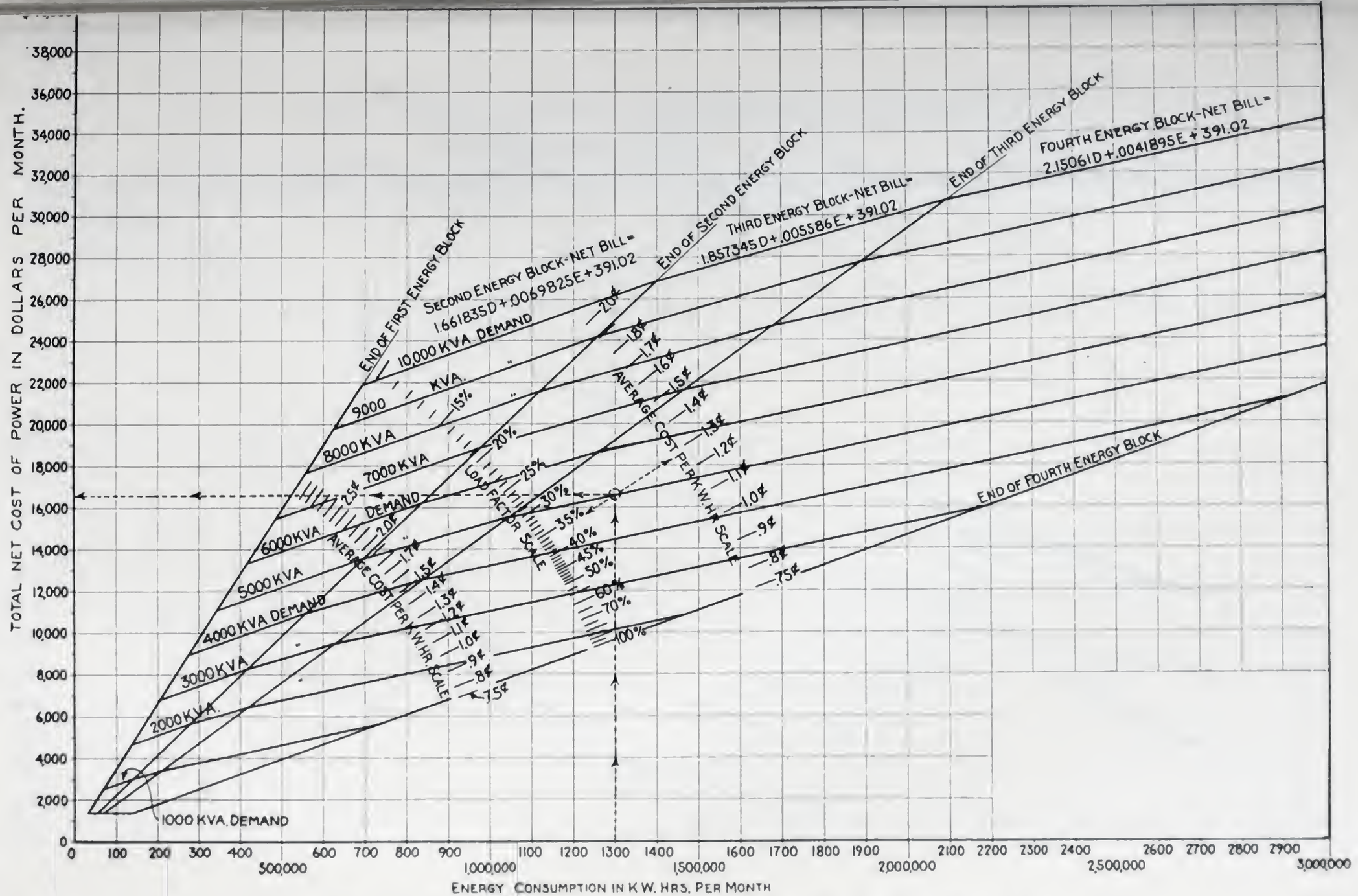

Fig. 2. Graphic Determination of Wholesale Power Costs, Schedule B.

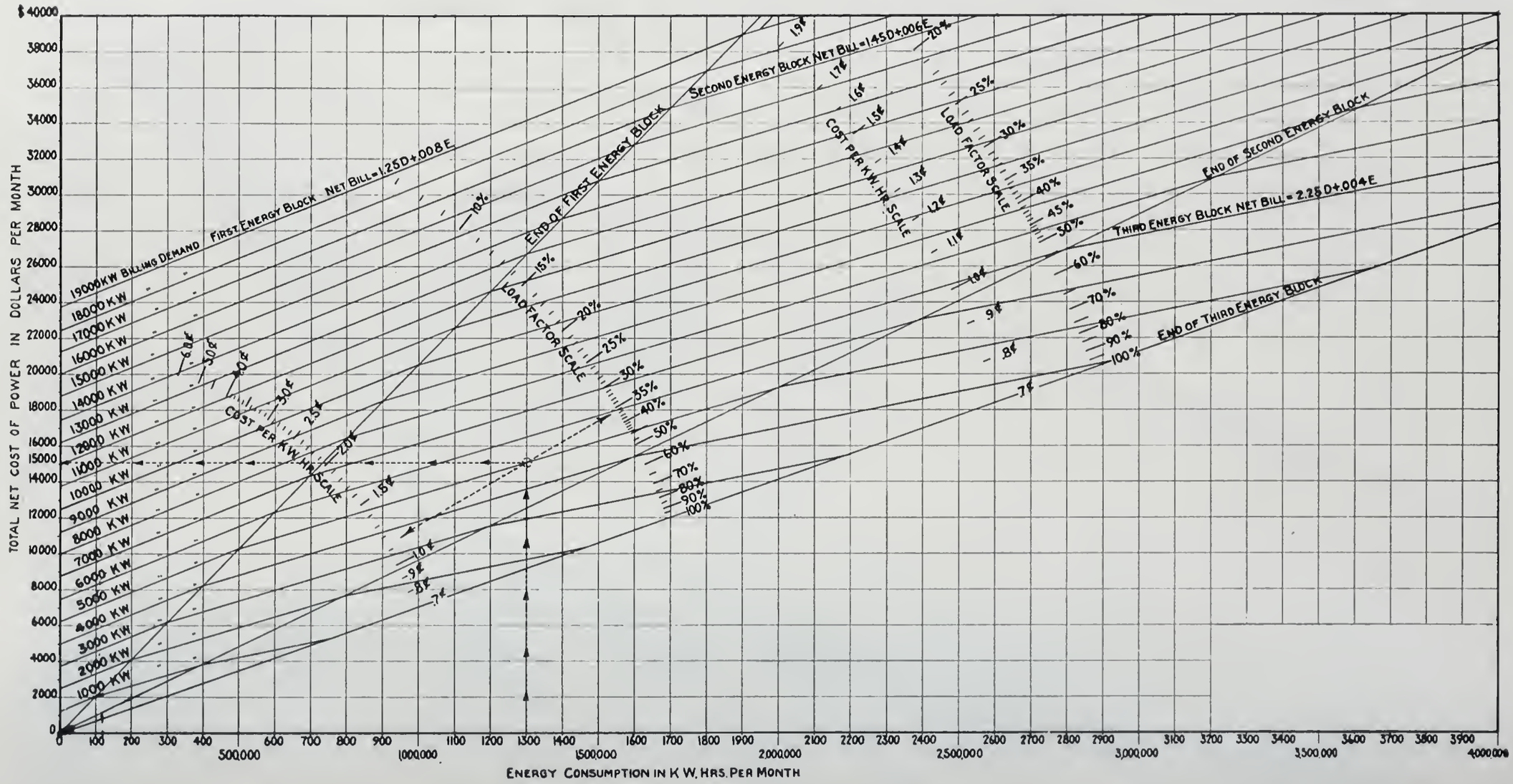

Fig. 3. Graphic Determination of Wholesale Power Costs, Schedule C.

TABLE I. ANALYSIS OF POWER BILL WHEN CONSUMING 1,300,000 KILOWATT-HOURS OF ENERGY ON A BILLING DEMAND OF 5000 KILOWATTS

Col. No.	1	2	3	4	5	6	7
Line No.	Name of schedule	Demand charge	Per cent. of total bill represented by demand charge	Energy charge	Constant charge	Total bill	Formulæ for net bill in dollars per month
1	"A"	1.58 × 5000 $7,900	45	0.007 × 1,300,000 $9,100	$386.60	$17,386.60	1.58 D + 0.007 E + 386.60
2	"B"	2.15 × 5000 $10,750	65	0.0042 × 1,300,000 $5,460	391.02	16,601.02	(Approximate) 2.15 D + 0.0042 E + 391.02
3	"C"	1.45 × 5000 $7,250	48	0.006 × 1,300,000 $7,800	0.0	15,050.00	1.45 D + 0.006 E + 0

D = Billing demand in kilowatts. E = Kilowatt-hours of energy consumed.

meter, which records the rate at which energy is used for each 15-minute period during the month by drawing lines similar to those shown in Fig. 4. In the average month, four of these lines are drawn

Fig. 4. Record of Demand Meter.

each hour for the 730 hours of the month, making a total of 2920 readings.

The utility company must be prepared at any instant to serve any customer up to the maximum of his contracted capacity; and, if the customer insists, through carelessness, ignorance, or for any other reason, on using a high demand at widely separated intervals of time, he prevents the utility company from selling a large part of the output of that capacity to someone else during its idle periods. The customer should (and rightly so) pay for that capacity which the utility company is forced to hold idle in order to meet comparatively infrequent calls for large blocks of power. The measured demand is, therefore, taken as the highest reading of these 2920 lines that appear on the chart for the month.

For a given amount of energy, each kilowatt of demand cut off the top of the high-demand lines, saves from $1.45 to $2.15 each month, as shown in column 7 of Table I, and, on the larger demands of 1000 kilowatts or more, it is quite unusual when at least 10 per cent. of carelessly created demands can not be avoided.

An essential item in the power bill, which is frequently overlooked, is the power-factor clauses. For example, Schedule B is what is known as a straight kilovolt-ampere schedule. In this schedule, the measured demand in kilowatts at the customer's switchboard is divided by the lagging power-factor which, in many cases, raises the billing demand to a very material amount over the measured demand. Suppose the measured demand of 1000 kilowatts is created at 75 per cent. lagging power-factor. The billing demand then becomes $1000 \div 0.75 = 1333$ kilovolt-amperes, and the *addition* to the power bill is 333 kilovolt-amperes times $2.15 for each kilovolt-ampere or $715.95 for each month. This is quite a penalty when you consider that the average bill for 1000 kilowatts demand is somewhere in the neighborhood of $4000 a month. Schedule C has a different basis for power-factor clauses. In this case, the customer is expected to maintain a power-factor between 75 and 85 per cent. lagging and the rates are developed with this in mind. No penalties are added unless the power-factor drops below 75 per cent., in which case the billing demand is increased over the measured demand in the ratio of measured demand times 75 per cent. divided by the actual power-factor. When the customer installs equipment which will maintain a power-factor greater than 85 per cent., the schedule offers a premium. In this case, the billing demand decreases from the measured demand in the ratio of measured demand times 85 per cent. divided by the actual power-factor. Suppose the measured demand is 1000 kilowatts with 100 per cent. power-factor. The billing demand then becomes $\frac{1000 \times 0.85}{1.00} = 850$ kilowatts, and the premium in the form of a deduction from the bill amounts to 150 kilowatts times $2.25, or $337.50 if the power is purchased in the third quantity block of this schedule.

The Schedule A allows a lagging power-factor of 75 per cent. without penalty, and offers a premium for any power-factor higher than this, the maximum premium being 8.8 per cent. of the amount of the gross bill if unity power-factor is maintained. This maximum premium would amount to $355 on a bill of $4000.

It is interesting to note in Table I the change which takes place in the power bills when full advantage is taken of the power-factor clauses in each of the three schedules. This is illustrated in Table II.

TABLE II. ANALYSIS OF POWER BILL WHEN CONSUMING 1,300,000 KILOWATT-HOURS OF ENERGY ON A BILLING DEMAND OF 5000 KILOWATTS AT 100 PER CENT. POWER-FACTOR

Col. No.	1	2	3	4	5	6	7	8
Line No.	Name of schedule	Demand charge	Per cent. of total bill represented by demand charge	Energy charge	Constant charge	Total bill before power-factor discount	Reduction due to 100 per cent. power-factor	Net bill as rendered
1	"A"	1.58 × 5000 $7,900	45	0.007 × 1,300,000 $9,100	$386.60	$17,386.60	8.819 × 17,832.80 $1,572.67 (1)	$15,813.93
2	"B"	2.15 × 5000 $10,750	65	0.0042 × 1,300,000 $5,460	391.02	16,601.02	.....	16,601.02
3	"C"	1.45 × 5000 $7,250	48	0.006 × 1,300,000 $7,800	0.0	15,050.00	$\frac{5000 \times 15}{1000} = 750$ $1,087.50	13,962.50

Note (1): On Schedule "A" the power-factor discount is computed as a discount from the gross bill before deducting prompt payment discount. This gross bill is the $17,832.80 shown above.

Having seen some of the principal factors controlling the cost of purchased electric energy, let us see what may be done to the power bills.

Fig. 5 is a typical set of demand curves for a plant operating with purchased power supplementing its own power-plant. The worst

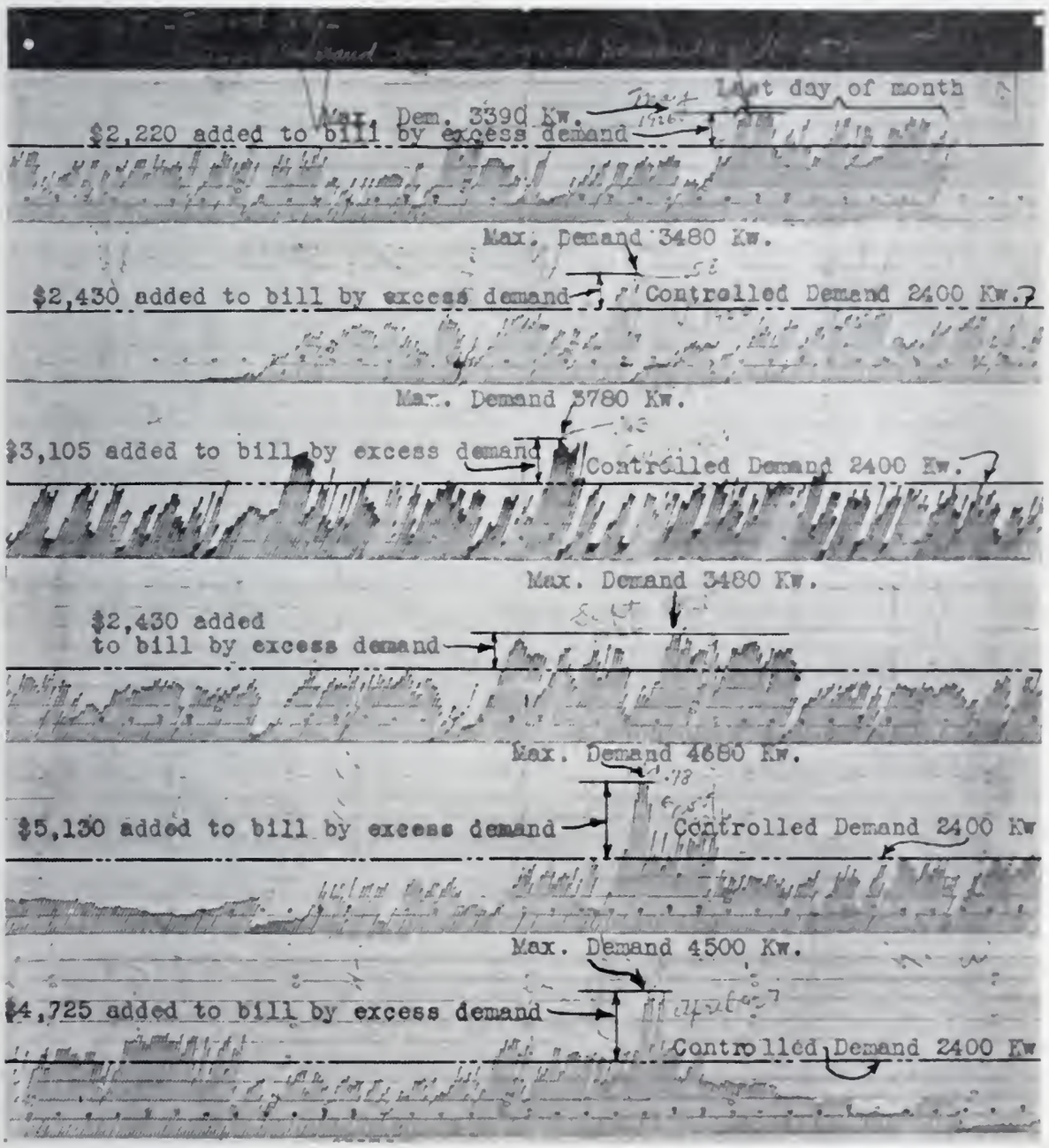

Fig. 5. Typical Demand Curves.

six months of one year were picked, and that portion of the chart which set the demand for the month was photographed. It is believed that with proper load-controlling devices, this plant could be operated on a demand of 2400 kilowatts, which has been called the "controlled demand." The charts tell an interesting story. Take the

first line, for example. Regularly at the end of each month, the department superintendents hear the cry from the manager—"Get those orders shipped and into this month's business." Note the answer of the superintendents in driving for the greatest possible output on the last day of the month. This is shown by the fairly uniform increases in the use of power. Also note the increase in the demand charge on the power bill. This increase, owing to the excessive drive at the end of the month, added $2220 to the power bill of that month. It is doubtful if the increase in output added $2220 to the profits of the plant for that particular day. Note in the second line how 1½ hours added $2430 to the demand charge of that month, and in the third line how 2¼ hours added $3105 to the demand charge. In the fourth line, one day added $2430, and in the fifth line, six hours added $5130, and it might be said that the entire amount was added in 1¼ hours. In this case, trouble on a steel-works turbo-generator caused it to be shut down. By order of the manager, production was maintained by throwing the entire load on the utility company. Again, it seems doubtful if the added profits of that six-hour period, due to maintained production, amounted to $5130. Spotty production is shown in the sixth line where $4725 was added to the demand charges as a result.

Purchased power at this plant cost for the year 1.35 cents per kilowatt-hour. Arrangements are now about completed to operate the plant-generating equipment in parallel with the circuits carrying purchased power, and to put load-control devices on the plant turbine, so that all swings in the load will be taken on the home system, and purchased power will be bought at a uniform demand and high load-factor.

An analysis at this plant showed that the "increment" cost of power on the home generator is 4.7 mills per kilowatt-hour, of which fuel represents 4.3 mills. Increment power on the utility company's schedule is 4.0 mills per kilowatt-hour; so that dropping the load on the plant generator and purchasing its equivalent from the utility company saves a small amount, even on the energy charges. As a result of this load control, it is expected that the average cost of purchased power will drop from 1.35 cents to approximately 0.8 cent, or a difference of 0.55 cent per kilowatt-hour. The plant purchases close to 18,000,000 kilowatt-hours a year, which makes a difference

in power costs of $99,000 a year. The load-control device will cost about $5000, and it seems to offer a rather handsome return on the investment.

As an illustration of what *can* be done in the line of controlling the load placed on a public utility company, a chart from another plant is shown. In this plant which turns out sheet bar, blooms, billets, slabs, etc., they have the usual run of direct-current mill table, shear motors, motor-driven machine-tools, etc. Under average circumstances, a load-factor of 50 per cent. would be considered as satisfactory. The plant was served by three very old engine-driven generators with governors not particularly quick acting. More electric power was needed, and, after looking over the situation, it was determined to purchase the additional energy, using a motor-generator set, and putting a load-control device on the set in order to limit the demands placed on the utility company.

The synchronous motor on the set was provided with sufficient field excitation so that the power-factor could be maintained at 100 per cent. In actual operation, the load control acts first in one direction, and then in the other, almost every second. The motor-generator set is inclined to "hog" any increment in the load, but the load control acts almost instantly and weakens the fields of the direct-current generator, thereby throwing the peak on the slower acting engine-driven generators. The result is about as near to perfect control as it is possible to get. Fig. 6 shows a typical demand chart. This demand is so constant throughout the entire month that the purchased energy was bought at a load-factor of 91.5 per cent. A glance at the schedule chart (Fig. 3) will show that under these conditions, energy can be purchased at an average cost of slightly less than 7.5 mills per kilowatt-hour. For a steel-works using purchased energy, on a regular tariff, this is considered very close to an engineering classic. The measured demand is 1120 kilowatts, power-factor 100 per cent., billing demand 952 kilowatts, and 634,000 kilowatt-hours of energy are consumed per month. The beautiful manner in which the results are accomplished certainly sets an example that every other purchaser of public utility energy will do well to strive to imitate.

Various power companies encourage their customers to use energy under special conditions by making concessions of one kind or another in their rate schedules, or in the method of figuring the

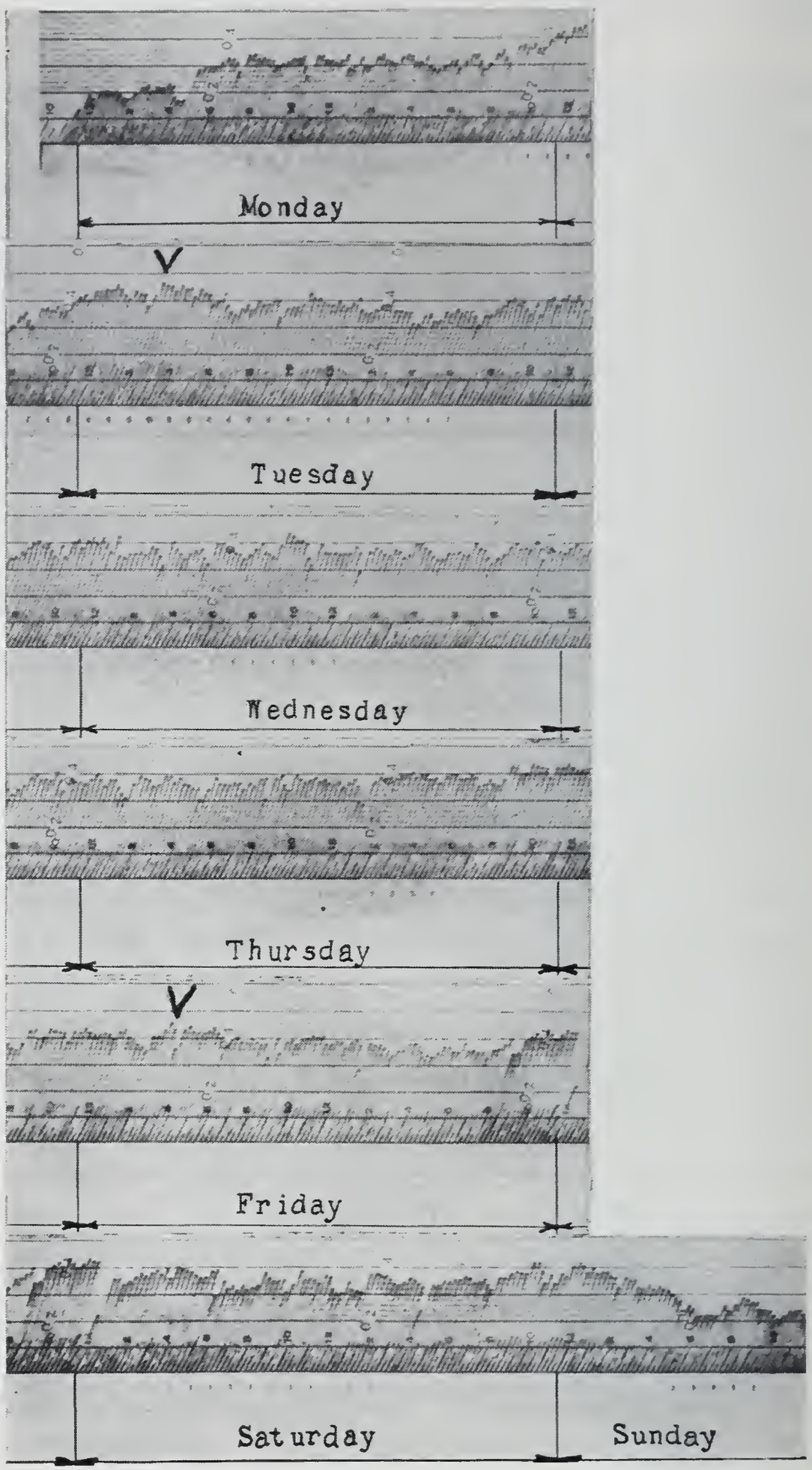

Fig. 6. Typical Demand Chart.

demand charges. For example, one company allows a customer to create a demand of 200 per cent. of its measured on-peak demand during the off-peak periods; that is, between 4:00 P. M. and 7:00 A. M. during the week, and from noon Saturday until 7:00 A. M. Monday. This encourages the use of energy during these hours.

The author had occasion a year or two ago to help a neighbor who was connected with a factory for the recutting of files, and who was complaining of excessive power bills. The most casual inspection of the plant showed a large part of the trouble. All the teeth on the old files had to be ground off before the new cutting was made. This was accomplished by six big wet-grinding sandstones, each some seven feet in diameter, with a 24-inch face. Eight or ten files were placed in a jig and the old teeth ground off, chiefly by a brutal application of main strength and awkwardness. The stones were started and stopped at frequent intervals. The rest of the plant offered an even and continuous load. By shifting the grinding to off-peak hours, the power bill in this plant was cut from approximately $500 to $300 a month, a saving of 40 per cent.

Sheet and tin-plate companies often resort to starting their big trains of cold rolls before 7:00 o'clock in the morning, particularly in winter when the neck grease is cold and the starting torque required to break them loose is very high. This avoids the penalty for excessive instantaneous peaks.

A great deal can be accomplished in cutting off the tops of peaks on the demand charts, even though a plant is depending on the utility company for all its power and has no generator of its own which can be made to take the peaks.

There are devices on the market known as "demand and limiters," or "demand limitators," which may be used in a variety of ways. These devices will automatically check up the use of energy as the end of the demand period approaches. If the continued use of power at the rate used in the early parts of the period will cause an excessive demand for that period, a secondary circuit is set in operation. This secondary circuit can be used to give warning, by blowing "Klaxons" or lighting red lights, or it may be used to drop automatically a part of the load which will offer the least interference with the operation of the plant, restoring this load to service when that particular period is at an end. For example, several rolling-mills have "Klaxons"

supplemented with red lights at the heating furnaces. If the demand has been unusually heavy for the first ten or twelve minutes of the 15-minute demand period, the "Klaxon" sounds and red lights burn. This is a signal to the rollers to finish rolling material that is already in the mill, and a signal to the heater to discontinue sending additional material to the mill until the red light is extinguished at the end of that particular period. This system does not interfere with output as would appear at first thought. The men soon learn to get out their tonnage at a steady and uniform rate and it is seldom that delays of more than a half minute to a minute are encountered.

Another idea which is now being employed by some quarrying companies is to place rather large compressed-air storage tanks near the end of their air lines. When excessive demands threaten, the secondary circuit actuates the valves on the unloading pockets in the cylinder heads of the air-compressors allowing the machines to "spin" on the line, and the compressed-air tools to operate on the reserve capacity of the storage tanks.

The unloading valves on service-water pumps are often used to cut off the demand peaks when the water system has a stand-pipe or other reservoir that will hold a few minutes' supply.

A very large use of the demand limiters is in connection with electric furnaces, particularly on the melt-down portion of the heats.

A little study of almost any plant will disclose some electric consumers whose operation can be interrupted occasionally, without noticeable effect on the production of the plant as a whole.

It is interesting to see how some utility companies bid for high load-factor business and how this phase is apparently ignored by others. In Fig. 7, the tariffs of the three schedules being considered are plotted using a 1000-kilowatt demand as a typical example. It is interesting to note that at 29 per cent. load-factor, Schedule B begins selling the last block of increment power at approximately 4.2 mills. At 56 per cent. load-factor, Schedule C begins selling the last block of increment energy at 4.0 mills, while Schedule A makes no particular bid for high load-factor sales beyond a 13 per cent. load-factor where it starts its block of 7.0-mill energy to continue to the 100 per cent. load-factor line.

It is the belief of the author that power sold in this last block is the most profitable power sold by a utility company and at the

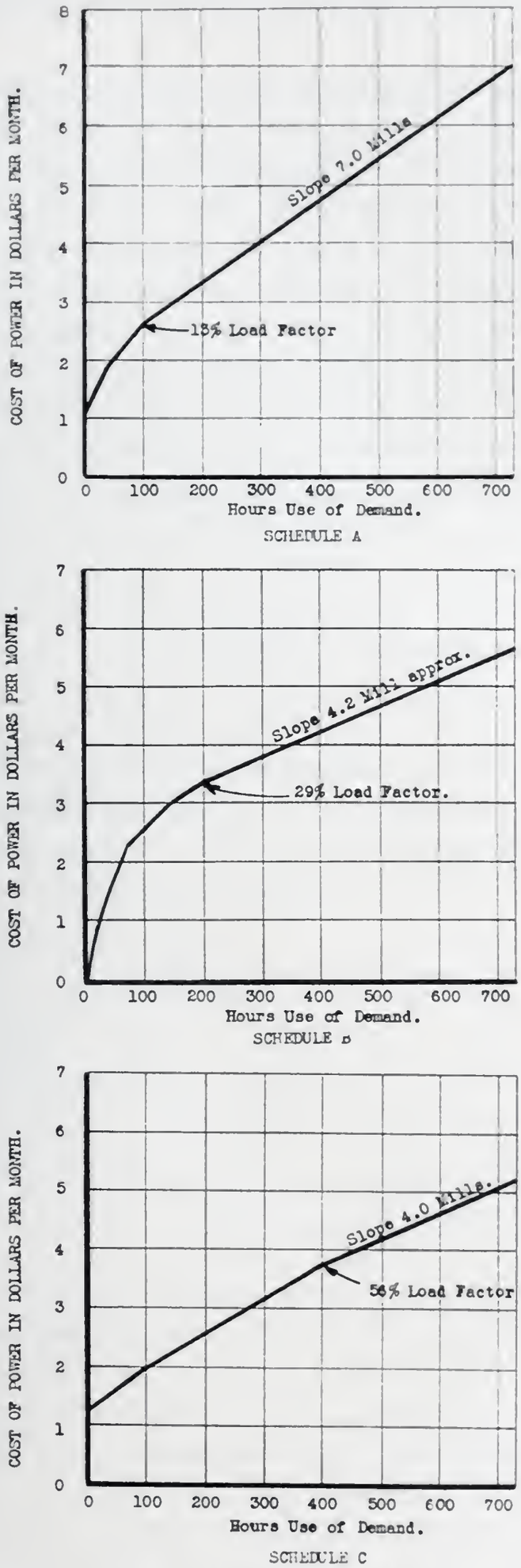

Fig. 7. Tariffs under Schedules A, B, and C.

same time the most profitable power purchased by a consumer. This low-cost energy at the end of such a schedule is, therefore, an excellent thing for everyone, including the community at large. A properly designed schedule automatically takes care of all costs, and allows the power company a fair profit at no matter what point on the demand line the energy is purchased. When the demands are high and the energy consumption is low, the power company has the benefit of considerable diversity among its customers. When the load-factor increases to a point where all benefit of diversity disappears, the power company is deriving sufficient revenue from the single consumer to carry all charges and have a profit. Beyond this point, where the fixed charges, maintenance and certain parts of the constant and increment operating costs are carried by the revenue derived from that particular load, the power company has only its increment cost for the increment energy. This increment cost, in most large utility power stations is slightly less than 2.0 mills per kilowatt-hour, most of which is represented in fuel. For this reason, power in the last block which is sold at 4.0 mills is slightly more than 50 per cent. net profit to the power company. It is, of course, necessary for the customer to pass through the first series of blocks before this large increment profit to the power company is possible.

It is often said that concerns having large loads can generate their own power from coal more economically than they can purchase power from a utility company that has long transmission lines to maintain, with the investment charges, transmission losses, and maintenance charges incident to these long lines. In order to consider this point, the author has chosen at random to set up typical costs for a hypothetical manufacturing plant having what the plant engineer would consider a 9000-kilowatt demand.

It would seem to be reasonably good engineering to install two 5000-kilowatt generators for service, and, inasmuch as the plant is isolated, a third 5000-kilowatt unit as a spare. The plant would probably install four boilers, with three operating, and the fourth as a spare. A station of comparatively small units of this kind, if the land values, sewers, intake, pumps and pump-house costs were included, would probably cost at least $123 per kilowatt of installed generator capacity, making a total investment of $1,845,000 in the

station. If fixed charges of 13 per cent. are placed against the station, the monthly fixed charges would be approximately $20,000.

With an average year-around boiler efficiency of 70 per cent., a reasonable steam rate on the turbine, and coal at $3.50 per gross ton, the cost of operating such a station would be fairly well represented by Fig. 8. In this figure, the cost of power in dollars per month is plotted as the vertical ordinate, and the energy produced as the horizontal ordinate. The method used to determine the costs shown on this figure is based on a paper delivered by the author last June before the Association of Iron and Steel Electrical Engineers,* in which he showed that the total cost of power could be divided into two parts —a constant cost which is independent of the production, and an increment cost which, within certain limits, is directly proportional to the production. The figure shows that at any load L the total cost of power would be shown at P as indicated by the arrow and dotted lines.

In this particular case, the constant cost of power is $28,000 a month, including fixed charges of $20,000 a month, and constant operating costs of $8000 a month. In order to obtain the total cost of energy for the month, it is necessary to add the increment cost of 4.0 mills for each kilowatt-hour produced.

In order to compare the cost of purchased power with power generated in a privately owned station, the upper cost line of Fig. 8 is repeated in Fig. 9, to which has been added the cost of electric energy purchased under the three schedules that have been considered, based on a 9000-kilowatt measured demand.

To make all conditions reasonable and comparable, a 75 per cent. power-factor has been used in each case. This is quite usual in the smaller generating plants. It is the base power-factor on Schedule A; it is within the range of allowable power-factors on Schedule C; but it requires considerable adjustment to fit Schedule B. In this last case, the measured demand of 9000 kilowatts is raised to a billing demand of 12,000 kilovolt-amperes.

The figure shows a number of very interesting facts: (1) that the so-called high-cost, low-load-factor, public utility power is in reality *cheap* power, if compared with the cost of producing the same energy in a private station; (2) that under almost any reasonable

Iron and Steel Engineer, 1928, v. 5, p. 278-290.

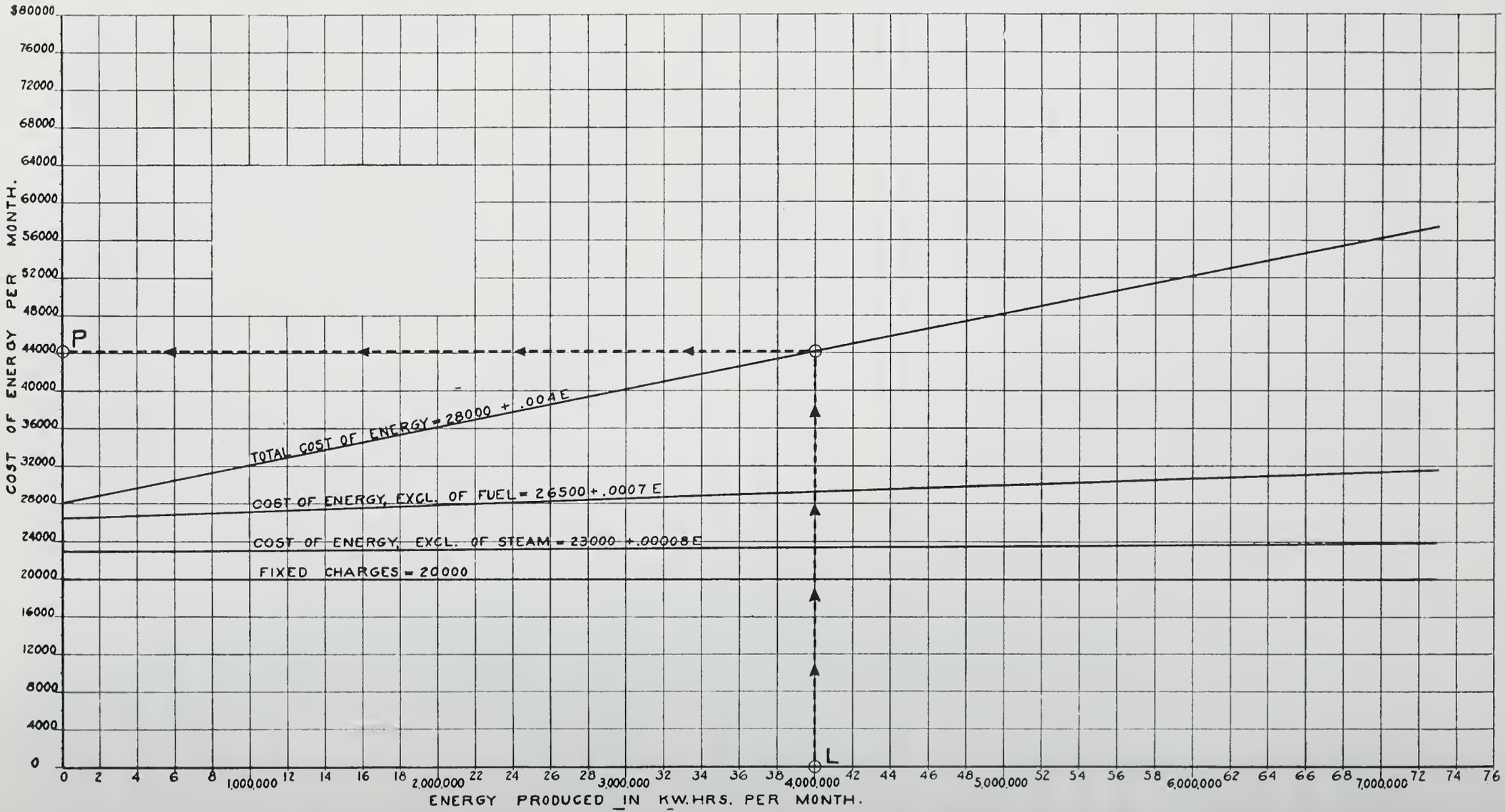

Fig. 8. Cost of Operating Isolated Coal-Fired Generating Station of 15,000-Kilowatt Installed Capacity. Boiler Efficiency 75 Per Cent. and Coal at $3.50 per Gross Ton.

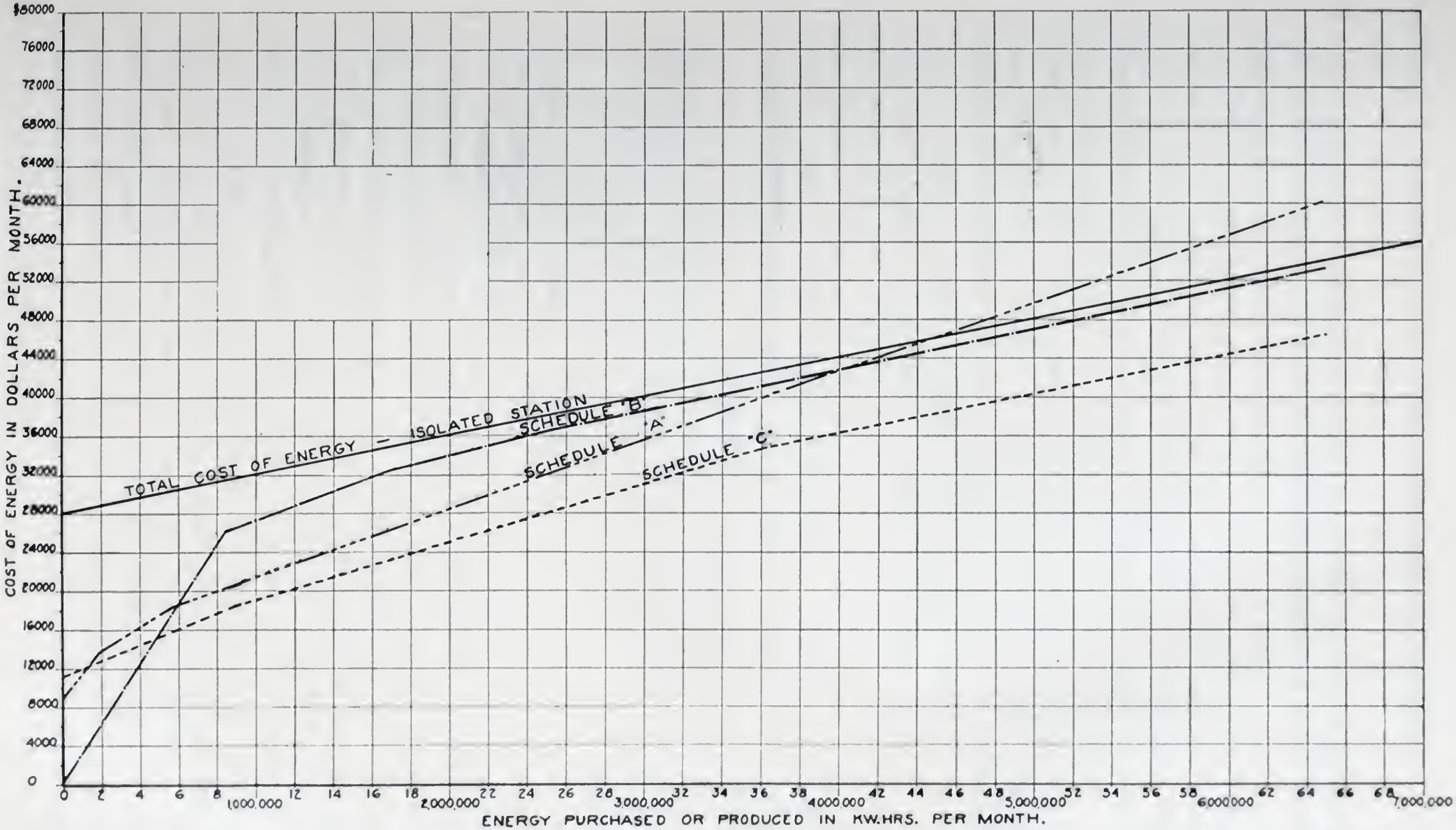

Fig. 9. Cost of Producing Electric Energy in 15,000-Kilowatt, Isolated, Coal-Fired Generating Station, Compared with Cost of Purchasing Electric Energy from Local Public Utilities at a Measured Demand of 9000 Kilowatts at 75 Per Cent. Power-Factor.

operating conditions, all the schedules considered offer energy to a customer for less money than he can build and operate his own station, as it is seldom that a private station will be operated at a load-factor much higher than 41 per cent. (the point where Schedule A crosses the cost line of the privately operated station); (3) in two cases—Schedule B and Schedule C—the rates are below the cost of the private station throughout the entire range of all possible loads.

These facts are true only when a private station is built solely for the purpose of generating electric energy, and when the price of coal is as stated—$3.50 per gross ton. Cheaper coal would not materially affect the constant part of the costs, but would affect the increment costs by flattening the slope of the cost line.

If large quantities of steam are needed for process work, or if large quantities of by-product heat are available, which if not turned into other forms of useful energy must be dissipated at its source, the situation is entirely changed and an almost infinite variety of possibilities and conditions presents itself. Each case of this kind must be examined and decided upon its own merits.

In closing, attention is called to one very common error, often made when comparing the cost of purchased electric energy with that generated in the consumer's privately owned and operated power-station.

The cost sheets of practically every manufacturing company show only the operating costs for the plant or department under consideration, and fail to take into account the fixed charges which cover interest, depreciation, amortization, taxes, etc. Inasmuch as these items are real costs, the public utility rates must of necessity include them in their schedules. The average purchaser of power looks only at his cost sheets and compares the cost of power as shown, with the amount of money he must pay a power company for the same quantity of energy, thereby completely losing sight of the fixed-charge item which does not appear on his own cost sheets. Such a comparison is obviously unfair and frequently leads to erroneous decisions. Furthermore, when money is once invested in a privately owned power-plant, the assets become frozen, and can not be liquefied at anything like par value, except by the continued use of the equipment during its normal operating period or life. While the same charges are paid to a power company, the consumer is called upon to

pay for only that part of the equipment which he *actually uses*, and he avoids fixed charges on idle equipment held as spares, which he would have in his own power-house.

If, for any reason, he decides to cancel his contract with the power company at any time prior to the completion of the period of normal life of a power-house which he *might* have installed, his fixed charges cease and his "investment" is liquefied at full par value at once and without effort on his part. It, therefore, appears to the writer that even with large loads, there are very few manufacturers who can afford to install a straight coal-fired power-station for the generation of electric energy in competition with power rates such as we have examined in this paper, unless the manufacturer has power as a by-product incidental to other manufacturing processes.

DISCUSSION

B. R. Shover:* Mr. Skinkle's paper brings out clearly and concisely a number of points which are of interest to both the buyer and seller of electric power. While his conclusions in regard to rate schedules are undoubtedly correct, there is still ample room for improvement, both in simplicity and in standardization of form, because from the almost unlimited variety, it looks as though each utility company prides itself on working out schedules different from all others.

It is self evident that low-load-factor power should command a higher rate than that purchased at a high load-factor, therefore practically all schedules are based on some form of demand, either distinctly stated as such or more or less camouflaged.

The term "demand charge" is usually explained as an amount representing the fixed charges on the equipment which the power company requires in order to supply a consumer. If this definition is correct, then the sum of all demands should not exceed the total power which the power company could supply for the duration of the demand period, unless the total revenue from this item did not exceed the fixed charges on the power company's entire investment. If the amount of fixed charges is exceeded by the total demand charges, then there should be a different explanation for the term "demand charge."

*Consulting Engineer, Pittsburgh.

A very common requirement in demand, which is severely criticized by the consumer, is one which penalizes him, frequently for the succeeding 11 months, just because he happened to have one month of good business. He reasons that since the heavier load was carried, there is no reason to believe that it could not be carried again nine or ten months afterwards. If this extra load could not be carried at a later date, it would probably be because of additional customers, and why should the power company be paid twice for carrying the necessary capacity. Again he says, I may never use that amount of power in any one month, in which case it is manifestly unjust for me to pay for it. Of late years some schedules have changed this feature so as to make it more fair to the consumer.

The "minimum monthly bill" requirement is frequently objected to, particularly by prospective power customers. Most people realize that fixed charges must be met, either for investment in their own generating equipment or in that of the utility company, but the latter must be paid each month, whereas the former need not necessarily be "written off" during a period of depression. Some form of an "annual minimum" would tend to overcome this objection, would make life easier for the power salesman, and probably bring additional business to his company with little or no loss of revenue.

Most power companies look with favor on efforts to reduce demands such as those shown in the paper, because high-load-factor business is preferable to low, and a satisfied customer is a very valuable asset. The cases cited are excellent illustrations of what can be accomplished by studying the effect of plant operation, particularly to the consumer who buys power under an 11-month demand penalty. Although conditions do not usually permit the remedies applied in these cases, there are but few purchasers who could not reduce their power bills by having a careful study made of their own plants.

Mr. Skinkle's conclusion in regard to purchased and locally generated power is rather surprising because it has been generally believed that there was always a certain load where the costs of power from these two sources were equal—that below that amount purchased power was cheaper, and above that, it was more expensive. His comparisons show the truth of both the general belief and the conclusion drawn in his paper. Compared with power purchased under Schedule A, locally generated power becomes cheaper after a

41 per cent. load-factor has been reached, while under the two other schedules and within the capacity assumed, purchased power is always cheaper. Evidently the rate schedule, the load-factor, and the amount of the load must all be considered in order to arrive at the correct solution of a particular case.

Rate reduction during the past 10 years has made possible the condition illustrated. In 1918 a study made for a small local steel plant showed that for an average power consumption up to and including 3000 kilowatts and a load-factor of about 45 per cent., purchased power was the cheaper. Some years later, estimates showed that the returns on an investment required for a 25,000-kilowatt station in connection with a works having blast-furnaces, steel plant and rolling-mills, would be only about four per cent. above fixed charges.

In 1925 a steel-works and rolling-mill scrapped a power-plant and contracted for its requirements because the total cost of power would thus be less than could be expected from adding the equipment necessary to generate a demand of 15,000 kilowatts.

In 1927 a very comprehensive power survey of a steel-works having by-product coke-ovens showed that with fixed charges included, power could be purchased at a rate lower than that at which it was then being produced from a 30,000-kilowatt station.

In a still more recent case, a steel company decided to purchase 25,000 kilowatts because the overall cost would be less than could be reached by adding the necessary generating equipment to an existing station.

Of course local conditions were a determining factor in all of the above cases; nevertheless they show a tendency to confirm Mr. Skinkle's conclusion.

Even where waste heat is available, care should be exercised to determine whether it is more economical to use it for power or for some other purpose. Custom seems to have decreed that waste heat in the steel industry must always be used for the production of power, but even time-honored customs can change. To-day the majority of combustion experts agree that the economical use for coal is under boilers and that gas should, wherever practicable, be used for metallurgical purposes. There have been cases where by-product coke-oven gas was burned under boilers and at the same time producer gas was

used in heating furnaces—a condition which probably does not now exist.

European plants are successfully using a mixture of blast-furnace and coke-oven gas in open-hearth furnaces. This mixture is now being tested in one furnace in America, where it is successfully competing with oil. There is also at least one case where blast-furnace gas is being tried in soaking-pits, and one where coke-ovens are fired with it. If this practice proves to be correct, a very large amount of power now obtained from waste heat will have to be produced from coal, probably at a higher cost than that for which it could be purchased, and thus become an example of Mr. Skinkle's "frozen assets." Steel plants considering the installation of generating equipment should give this point serious consideration before making large investments for producing power from blast-furnace gas.

The way in which the officials of many manufacturing plants, and particularly steel-works, look at the question of purchased power, is rather peculiar. If they think they can generate their own power "cheaper" than they can buy it, that seems to them to be the proper course, regardless of the fact that an expenditure for turning out their own product which showed only equal returns on the investment, would not be given any consideration whatever.

Comparison of costs is very likely to be misleading, unless such costs are kept under the same system; otherwise, the figures are not correctly comparable. As an example, the executive of a manufacturing company protested to the utility company that his power costs per unit of product were nearly always the highest in the trade association of which his company was a member. Inspection of the supposedly comparable costs revealed first that the figures represented operating costs only, fixed charges being omitted entirely. Investigation showed that about half of the companies whose costs were represented, either used steam direct in engines or generated their own electric power, and that all purchased power, except for this particular company, was metered on the primary side of the substation.

This man had previously learned that, for his works, motor drive with purchased power was cheaper, all costs included, than steam-engines, but had never realized the effect of fixed charges on transformer substations. He was shown that his rate for *primary*

power was lower than the rates enjoyed by any of his competitors, that under this condition his costs, now really comparable, would be next to the lowest, and a survey of his plant showed where the excess power was used. He purchased the substation, corrected the abuse of power, and is now a satisfied purchaser. While "figures do not lie," they often do most woefully misrepresent the facts.

G. E. Stoltz:* It is evident that Mr. Skinkle has made a very thorough study of the cost of purchased power in accordance with the schedules published by certain public utility companies. The graphic analysis as given in the figures accompanying his paper enables one to obtain a very clear conception of all the phases of these various schedules.

Power-factor and load-factor should each have considerable influence on the cost of purchased power to large industrial users.

During the last 15 years, covering the period during which power has been extensively purchased by large industrial users, there has been a gradual change in the design of electrical apparatus used by the purchaser of public utility power. In general the standard synchronous motor as built five years ago, having a pull in torque of about 50 per cent. full-load torque, would develop a rated starting torque of one-fifth the rated kilovolt-ampere input. To-day the rated starting torque is a third of the present full-load rated kilovolt-amperes. This represents an increase of 70 per cent. Special designs can even exceed this value. It has been felt that the induction motor is the only design adapted to a large number of industrial applications. This is due to the superior starting characteristics of the wound-rotor induction-motor over that of the synchronous motor. The synchronous motor of course is just as capable of handling the load after the driven unit has been brought up to full speed. This of course is on the basis that there is no need of equalization of input by the use of fly-wheels. It is unfortunate that we have not had a motor of practical design, incorporating the starting characteristics of the wound-rotor induction-motor and the ability to operate at 100 per cent. power-factor after it has reached normal speed. Designers of the synchronous motor have been endeavoring to improve its start-

*Manager, Industrial Engineering Department, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

ing and pull-in characteristics and considerable advance has been made, particularly within the last few years. We have no reason to believe that the ultimate has been obtained, so that the use of the synchronous motor on industrial loads can be expected to be extended still further.

The steel industry has purchased the following number of synchronous motors for rolling-mill drive:

	Number of motors	Horse-power capacity
1923	2	1,000
1924	6	2,500
1925	14	19,450
1926	3	12,000
1927	20	38,200
1928	38	46,450

The increasing use of synchronous motors relieves the public utility company of the burden of providing an unusual capacity in transmission lines and transformers and therefore makes the customer's load more attractive.

Where it is not possible to obtain the corrective kilovolt-amperes in motor capacity, use has been made of motor-generator sets, rotary converters and synchronous condensers, but more recently static condensers have been developed. A number of very satisfactory installations of static condensers have been made. There are no wearing parts to maintain, the losses do not exceed one-half of one per cent., and the deterioration of properly designed equipment is negligible.

The development of the static condenser and the improved synchronous motor has been brought about for no other reason than to enable the industrial plant to accommodate its requirements more advantageously to economic service from the public utility.

The second phase of this subject of the economy with which the public utility can serve the industrial customer is load-factor. There are many methods of adjusting the operation of a plant to relieve the central station of the peaks during the period of maximum load. Mr. Skinkle has suggested a device which will give a signal previous to the end of the 15-minute period, and allow the dropping of part of the load. Recently in making a study of further electrifying a coal-

mining property which was using power on the basis of 1.2 cents per kilowatt-hour, it was found that if the steam-pumps were electrified, part of them being used 24 hours a day, the demand during the day period would be increased from 3000 to 5500 kilowatts. While some pumping would have to be done during the day, for breaker water, the remainder would be collected in sumps and this water removed during the 16-hour, off-peak, night period. With this arrangement the demand during the night period would be increased from 1200 to 6800 kilowatts which would be in excess of the demand for the day or peak period. The power company has agreed to disregard peaks that might be established during the off-peak night period.

This we feel is a logical arrangement both for the power company and the industrial customer. Under this arrangement the cost of power per kilowatt-hour for the month is reduced from 1.2 cents to 0.8 cent. With such an arrangement, the only increase to which the public utility company would be liable is the possibility that it would be required to increase the capacity of the step-down transformers if these are furnished by the central-station company. If the customer furnishes the transformers, usually the transmission line which would serve other customers would not be changed and we see no reason why the central-station company should establish the demand during the off-peak period.

Mr. Skinkle has cited one example where engine-driven generators were used to absorb the peak-loads and by means of a load regulator the power purchased from the public utility was kept at practically a constant value. Unless there is some other reason for having these steam-engines in operation, we doubt very much if this customer could economically afford to keep the steam-engines in operation to carry this portion of the load. This point is well illustrated by the curves in Fig. 9 for a very low load-factor and it will also be noted that Mr. Skinkle states that low-load-factor load is relatively the cheapest power that can be purchased.

Mr. Skinkle has compared the cost of developing a 9000-kilowatt load either by the installation of a generating plant consisting of three 5000-kilowatt turbines, one being used as a spare, or purchasing the entire load from a public utility. He shows that it would be more economical to purchase power unless the load were in excess of 4,500,000 kilowatt-hours and power were to be purchased in

accordance with Schedule A. It seems to us that if a generating station were to be installed to carry this load it should be possible to work out a more economical arrangement by having the customer install two 5000-kilowatt turbines and depend upon the power company for spare capacity. The public utility company can carry this spare capacity much more cheaply than the customer, so that the payment to the power company for this spare capacity should be less than the fixed charges on the extra turbine. It would be interesting to have Mr. Skinkle add a set of curves to Fig. 9 showing the total cost of energy with the spare capacity purchased from each of the three power companies considered.

F. M. Van Deventer:* I did not come here for the purpose of discussing the paper. I received a copy of it yesterday, and read it on the train late last night. Admittedly, I examined it critically, looking for any points which might warrant criticism, but found none; and I think I know the reason. I had the privilege of being associated with Mr. Skinkle for a number of years, and it was our custom to compare notes and views freely. Through tolerant and constructive argumentation we reached mutually agreeable conclusions, and in a majority of cases, he convinced me wherein I was wrong. As we worked jointly on many purchased power problems, it is not surprising that I fail to find fault with his method of analysis in the present paper, for our differences of opinion were threshed out long ago.

I think of only one point which I should attempt even to amplify, let alone criticize, and that is that each case is a law unto itself, and must be considered in the light of local conditions. Generalized conclusions are dangerous, since two identical cases seldom or never occur. I shall submit a brief example.

In my work in the Pittsburgh district it was my privilege to make a number of analyses to determine whether it was more economical for certain isolated fabricating or manufacturing plants to purchase power from the public utility or generate it locally; and by the way, it was the difficulty of interpreting the rate schedules and the effect of load characteristics upon rates in this work that resulted

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in the conception of the rate charts and formulæ referred to by the author.

These studies seemed to warrant the general conclusion that in cases wherein waste heat was available or wherein low-pressure process steam was required, power was most economically obtained by local generation; but, if neither waste heat nor process steam were involved, power could be more economically obtained from the utility company.

Recently, however, I examined an analysis which proves a paradox to the foregoing conclusion. In this case a large quantity of steam was required for process use, and a considerable quantity of power also was needed. An engine of rather ancient vintage was used to generate a portion of the energy, and the remainder was purchased. It was proposed to purchase a modern and economical engine and produce all the energy required from the steam generated for process work, on the assumption that money would be saved, and it would seem that such would certainly be the case. It was found, however, that due to the high carrying charges on the necessary investment, particularly in conjunction with a low capacity use factor (about 20 per cent.), the cost of combined operation when carried out in that manner would exceed the cost by the present system in which most of the energy is purchased.

May I say, in deference to the fairness of most present rate schedules, that I have found several cases in which money was saved by abandoning existing isolated equipment and substituting purchased power, even though the equipment had been completely amortized and, therefore, need not be handicapped by such charges.

Mr. Chairman, the principal reason for my presence here is to pay my respects to your retiring Chairman. Having done so, and assured you that this time I have come without a chip on my shoulder, I shall anticipate another opportunity to present something of a more constructive nature.

G. W. Ousler:* Mr. Skinkle has just delivered an extremely interesting paper containing some very valuable information, the preparation of which must have taken considerable thought and attention. It contains some very pertinent facts, which all present or

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potential users of power should seriously consider before deciding upon the source of power for their particular installations.

The underlying principle in Mr. Skinkle's paper is that purchased power, in a majority of cases, is cheaper than energy delivered from a private plant. To prove his case he has chosen some general power rates of various companies in this vicinity and made a comparison between these rates and the cost of private plant energy.

As Mr. Skinkle points out, each public utility company has various rate schedules to meet special and local conditions of specific consumers. The rates which he has chosen are the general power rates. Others are available, which may be more favorable where the conditions, applicable to these other rates, can be met by the consumer. For example, there is the use of service on off-peak, seasonal load, etc., which, if applicable, are advantageous.

Mr. Skinkle has also emphasized certain other points which are extremely important, and which have a direct bearing on the cost of energy to the consumer. For example, a customer with a good load-factor is entitled to a better rate than a customer who has a correspondingly poorer load-factor. On the other hand, a customer with a large demand earns a lower rate than a customer with a smaller demand under the same conditions. Power-factor has also an important bearing on the cost of energy to consumers as it generally determines the demand at which a customer is billed even though the measured demand may show a lower amount.

The question of elimination of abnormally high peaks, which affect the billing demand and load-factor and the resultant cost to the consumer, is a very important item for each customer. On our own system we have some customers who watch this matter very carefully and others who are correspondingly careless. The former type of customer, in many cases, uses "demand limitators" to cut off the energy when its use would create an abnormal peak, and in this manner he keeps down both the measured demand and the billing demand during the entire monthly period. In this way an extremely good rate results, which, as I have pointed out, he earns for himself. The utility company can not, of its own accord, give a low rate to a customer who does not himself earn it. In other words, the utility company sets up the machinery for low power costs and if the cus-

tomer, in turn, will intelligently handle his load, he can earn for himself that which the company offers.

Mr. Skinkle has brought out a very important point, in comparing purchased power with costs in private plants; that is, the inclusion of all charges in private-plant installations in figuring the cost per kilowatt-hour. In order to determine correctly the cost of energy from a private plant, it is necessary to include, not only the operating expenses but the fixed charges, depreciation, taxes, amortization, etc. Too often these charges, other than operating, are neglected and results are not accurate.

In conclusion I would like to compliment Mr. Skinkle on his very fine, clearly written paper on a subject which is most important, and I recommend its study to all consumers of power, to the end that serious consideration be given to the entire cost of energy from a private plant as compared with purchased power, which I am sure will prove that the latter is generally more economical than the former.

A. G. Darling:* Mr. Skinkle has presented a very interesting exposition of public utility energy rates, and given a valuable interpretation of their application, showing, at the same time, methods of using them to the best advantage. The paper indicates a thorough knowledge of the subject on the part of the author.

Due to the fact that the cost of power is usually a relatively small percentage of total cost of the industrial companies' product, the subject does not receive as close attention on the part of the industrial plant executives as some other elements of the total cost. Of late years, the younger power engineers, due to their better training in technical schools and in the industries, have brought their thought and study to the subject, with the result that marked improvements have been made in the reduction of cost of power. On the other hand, the public utilities have a considerable advantage over the industrial plants, because power is their one main product and they have concentrated not only on the cost of power but also on the cost and best methods of marketing power. Their bulk production, together with the advances which have been made in power generation, transmission, and distribution, have all tended to assist the

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public utilities toward energy at low cost at a profit to them and at a rate to the consumers, which has expanded the use of electricity at enormous rates.

A decided trend toward higher efficiency and, thus lower cost of power, has been noted in the past few years for plants of smaller size, such as would be general in industrial use. The most marked improvements have been in boiler efficiencies, by the use of higher steam pressures and temperatures, and in the efficiency of steam-turbines using these higher pressures. The margin between the cost of power as produced in the industrial plant and cost of power as sold by the public utilities is constantly being reduced due to the improvements incorporated in the industrial power-plants. A better understanding of the power problem on the part of the industrial plant executives, together with a more sympathetic interest from them, has permitted the plant engineers to put into effect the savings made possible by these improvements.

The subject of power-factor, which has been brought out by Mr. Skinkle, is now generally understood by operators, and there is to-day not much excuse for a power-factor penalty being executed by the public utilities. Using Mr. Skinkle's sample figure of $2.15 per kilovolt-ampere of monthly demand as a penalty for low power-factor, it is not difficult to see that power-factor corrective apparatus is easily justified. His figure, when multiplied by the months of the year, gives the yearly penalty of $25.80, which, capitalized at 13 per cent., results in a possible investment of $198 per kilovolt-ampere. The losses contingent upon rotating synchronous condenser capacity will range from 2½ per cent. to 7½ per cent., inversely as the capacity of the condenser increases. Assuming that the condenser is large, losses per kilovolt-ampere of installed condenser capacity at 2½ per cent. will amount in a year to approximately $3, using the rates mentioned by Mr. Skinkle. Comparing this with the actual cost of synchronous condensers, we find that the investment is well justified on the basis of condensers costing between $5 and $8 per kilovolt-ampere of capacity installed. In addition to the correction of power-factor by means of large units, such as synchronous condensers, operators will find that motive power is available for almost any application which either has an inherently high power-factor or which can be supplied with corrective capacity sufficient to take care of such

other inductive loads as can not be designed with unity or leading power-factor.

Mr. Skinkle's study of the limitation of peaks (improvement in load-factor) has simultaneously been made by a number of other investigators, with the result that they have found classes of apparatus and control which will assist them very materially in obtaining high-load-factor power rates from public utilities. Steam-turbines as now designed are extremely adaptable to control which will be responsive to other requirements than speed. Some of the interesting cases of this type of application are:

1. A 15,000-kilowatt steam-turbine taking the swings of a large rolling-mill which requires from half to full capacity of the turbine, using wattmeter control of the steam-inlet valves. This unit has been in operation for a number of years.

2. Steam-turbines responsive to boiler pressure which varies in accordance with available waste heat.

3. Steam-turbines responsive to slight variations in system frequency, which, if they occur, would indicate the advisability of changing the operation of the turbine from a non-condensing type to a condensing type in order to insure electrical service and, if a further variation in system frequency occurs, the controlled unit is isolated to its own load. One particular application of this type of control is for power-station auxiliaries, and another application is that of an industrial plant operating its generators in parallel with an outside source of power which may be subject to outages or disturbances which can be eliminated from the industrial system by permitting its own generating equipment to be segregated from the outside source at the time of the outage.

Many other instances might be cited, varying from types of indication interpreted by such means as will furnish large amounts of power for the operation of control devices to other types of indications which can be measured only by air pressure in inches of water.

Where the frequency of two systems is different, such as often occurs when steel-mills using 25-cycle frequency are connected to public utilities whose normal frequency is 60 cycles, it is possible to control the interchange of power by means of induction-motor and synchronous-motor frequency-converter sets having special types of control. This design of equipment permits not only the controlling

of the load interchange, which can be set at a constant value or varied in accordance with some predetermined schedule, but also permits control of the power-factor of the power taken from the public utility. In many cases the two systems so connected consist of a quantity of generating units which share the load of their system in accordance with the regulation of their governors. The two systems may be operating successfully when isolated but, when paralleled through an inflexible tie, will have considerable difficulty in regulating the power interchange. The type of control mentioned makes it possible to continue the operation of the two independent systems without change in governor regulation, and at the same time allows the control of power interchange between the two systems.

The author of the paper presents comparisons of power costs as purchased and as generated in relatively small isolated plants, which it is distinctly understood are based on condensing operation of the isolated plants from fuel purchased at market prices. In his paper he recognizes the fact that, when there is a change in the basic conditions of condensing operation and purchased fuel, the conclusions reached by him will be materially changed. It so frequently occurs that the industrial plant has sources of waste heat, or requires heat in some form in process, that these cases can not be neglected in comparing the cost of purchased power with that of isolated power-plants. In fact, the National Electric Light Association has recognized these conditions in its official reports. The subject is so broad that no attempt can be made in this discussion to present it comprehensively, but some of the essential facts will be briefly considered. The situation is exemplified by the fact that a majority of the turbine generator units—7500 kilowatts and below—at present manufactured in this country, are built for either complete or partial non-condensing operation. A very large amount of electrical energy is obtained from these types of power-generating units in the industrial field.

The steam required for building heat alone is often a source of considerable power. Where steam is used as well for process work or for low-pressure prime movers, an additional source of energy is made available between higher boiler pressures and process pressures. This fact has worked out to the advantage of the industrial plants, as it has brought into use boilers of higher efficiency, higher pressure, and higher temperature. Expansion of steam requirements or the

replacement of old boilers is another fertile field for the introduction of boilers of higher pressure and the saving in efficiency resulting from their use.

In addition to the energy available from process or heating steam, there are many plants which have such sources as excess blast-furnace gases, waste heat from various processes, and heat from waste products of manufacture which may be burned as fuel. Neglect of these sources of energy can result only in a cost of power which is not commensurate with the cost of purchased electricity. Many industrial plants have recognized these sources of energy and have advantageously expanded their use. Some have gone so far as to offer the excess electrical energy available to the public utilities who are more and more inclined to accept this energy alone or on an interchange basis, realizing that it not only obtains for them low-cost energy to reduce their peak demands, but also retains for them an outlet for their power, which might otherwise be entirely lost. Such cases should be investigated and settled on their merits.

The subjects mentioned are worthy of a much more comprehensive discussion. Mr. Skinkle has handled this subject in such an excellent manner that it may not be amiss to offer the suggestion that he supplement his paper, at some not far distant date, with further information along the other lines suggested herein.

G. L. Simpson:* Mr. Skinkle's paper came to our desk at a time when we were engaged in plotting a number of our rates applicable to electric furnace work.

The possibility of developing equations to express most power-rate schedules mathematically was first brought to our attention in this paper. It should certainly prove a godsend to those who have much of this sort of calculation to do, and we should like very much to see some further developments along this line. With a prospective power user, discussion of the various effects of change in demand and energy consumption and the net result on his power bill can be much simplified by means of such an equation.

Fig. 10 shows three of the more recent power company rates plotted on a basis somewhat different from that given in Mr. Skinkle's paper. We have used an 85 per cent. power-factor as being more

*Pittsburgh Electric Furnace Corporation, Pittsburgh.

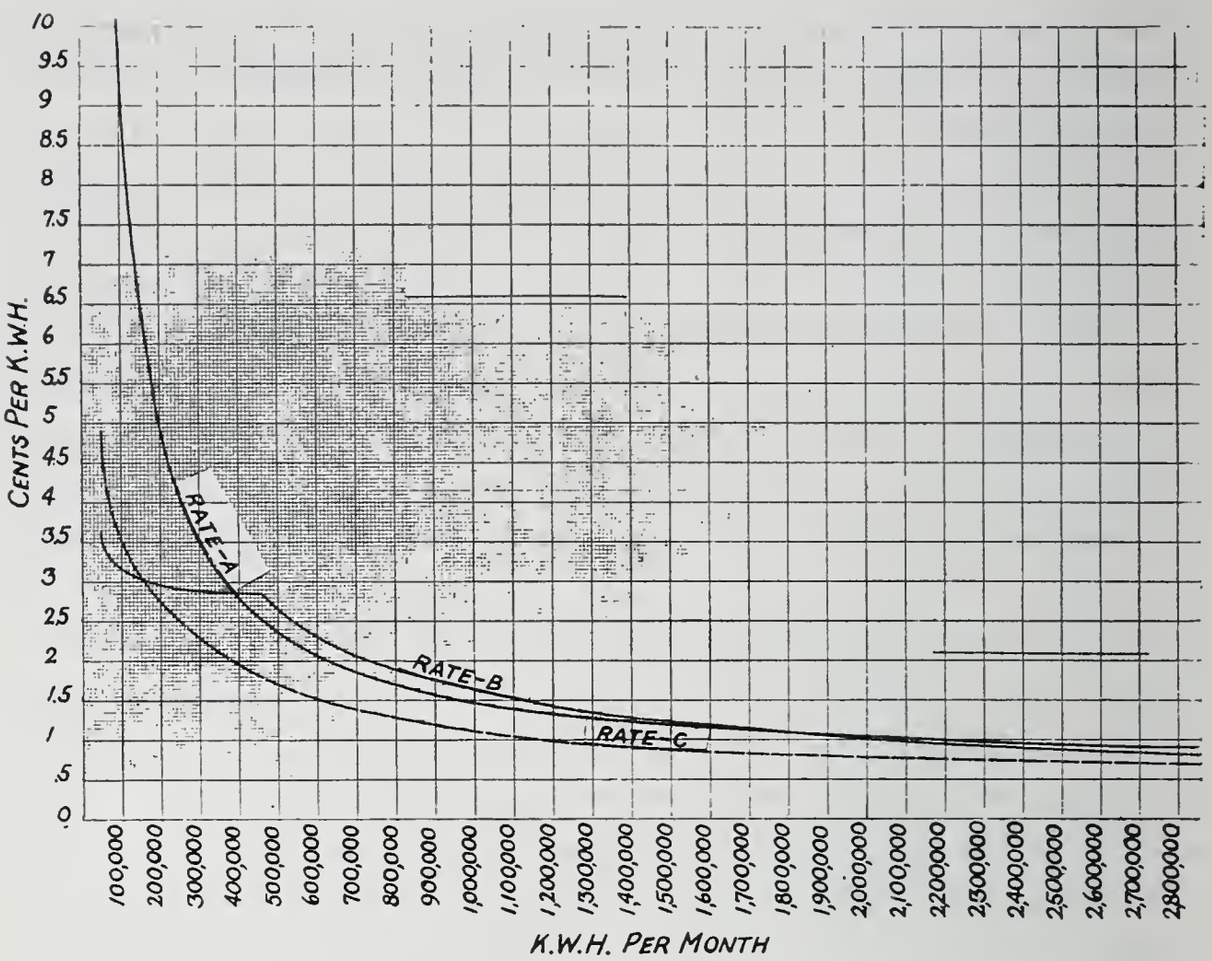

Fig. 10. Modern Power Rates Available for Electric Furnace and Other Steel-Mill Loads.

typical of large motor loads and electric furnace installations; and, instead of plotting the total power bill as ordinates, we have plotted the cents per kilowatt-hour, since the average power user is accustomed to comparing the price per kilowatt-hour.

The upper of the three curves shows the rate available for 5000-kilowatt load at 85 per cent. power-factor in a mid-western location. This rate has been considered an attractive one. The two lower curves show rates available in a large industrial district plotted on the same basis. It is interesting to note how the progressive power rates are tending to lower figures as the power loads grow.

W. E. MOORE:* Mr. Skinkle has covered the subject so unusually well that there is very little room for discussion.

Mr. Skinkle uses the words "demand charge." That is a phrase which we, as central-station men, used to try to avoid, for our custo-

*Consulting Engineer, Pittsburgh.

mers all seemed to think it was a kind of peremptory and unreasonable demand. We therefore coined the expression, "readiness-to-serve" charge, seeking thus to make it plain that the fixed charge is a charge based upon the cost to the power company of its capital for fixed charges necessary to prepare it to serve the customer's power demand.

Mr. Skinkle has made quite plain the importance to the customer of watching the load-factor and of watching the unusual and frequent peaks which lower his load-factor and increase his average cost per kilowatt-hour. This precaution is a far more important matter, in the way of keeping down the bills for central-station power, than the average consumer realizes. Fortunately, there are on the market several load-limiting devices (such as the "Limuter") which enable the customer to cut off or limit the unusual and exceptional load peaks without materially interfering with his operation and thus keep down the "readiness-to-serve" or demand charge and lower his average cost per kilowatt-hour and his monthly power bills accordingly. These devices can now be secured in a number of forms, at comparatively low cost, to suit almost any usual operating conditions.

Amongst users of central-station power, there is a prevalent opinion that the "readiness-to-serve" or demand charge should be based on kilowatts instead of kilovolt-amperes, and that the latter method, which is becoming more prevalent, is unfair and unjust. As a matter of fact, the method of rating "readiness-to-serve" charges on a kilovolt-ampere instead of a kilowatt basis is quite fair and logical, for the power company has to make an investment not only in its electric generators, but also in its step-up and step-down transformers, its lines, distributing transformers, and distributing system generally that is proportional to the kilovolt-ampere and not proportional to the kilowatt demand. It is therefore quite logical that the power company should base its "readiness-to-serve" charge on the kilovolt-ampere basis.

Power companies having large central stations advantageously located as regards supplies of economical water and fuel, have a great advantage in power-station operating costs as compared to the smaller industrial power-plants. By aggregating large amounts of power in one or more power-stations connected into high-voltage power-transmission systems, they are enabled to operate their plants with

high-class attendance to mechanize the various methods of handling fuel, ashes, etc., and to improve the load-factor on the plant very materially, and by means of large generating units improve the thermodynamic and operating efficiency of the plant to the highest practicable limit, and at the same time economize on the amount of reserve machinery capacity required to keep the plant in continuous operation. These are advantages that the ordinary isolated industrial power-plant cannot utilize to nearly the same extent. However, when it comes to the total cost of power delivered to the consumer's motors, the advantage in favor of the central station's low generating cost is not carried through to anything like the same extent, for usually the investment cost in the power company's generating plant is a third, or less, of the total cost of the power company's system for delivering power to the consumer. Furthermore, the power company must, in its system, stand the losses of step-up and step-down transformation and losses in transmission of power over long distances.

It is also true that the industrial power-plant, while far less efficient than the large central-station power-plant, can also be installed at a considerably lower cost per kilowatt of generating capacity, which tends to compensate for its lower thermodynamic and operating efficiency.

One point that has not been brought out is the matter of diversity factor as an economy to the central-station power companies operating large power systems covering large areas and embracing a great many consumers having diversified loads. By diversity factor is meant the peak-load on the central station as related to the sum of the loads demanded by its various consumers. It is seldom that the public utility does not have a diversity factor ranging from 70 per cent. up to 200 per cent., or more. This means that it economizes in its investment in the power-station, the high-voltage transmission lines, and the step-up or step-down transformers in somewhat the same ratio. This great economy to the central-station power companies by reason of the diversity factor has enabled the central station to reset the "readiness-to-serve" or demand charge to its consumers once a month, and otherwise liberalize the fixed charges to the customer. Except for this advantage to the power company it would be logical to reset the demand peak registration at much less frequent intervals.

W. B. Skinkle: On one or two points which have come up in the discussion of this paper, some further elaboration seems advisable.

Near the end of his discussion, Mr. Stoltz raises the question of the advisability or the economy of keeping old steam-engines in operation in order to reduce the peak demands on the purchased power. Quoting from Mr. Stoltz: "This point is well illustrated by the curves in Fig. 9 for a very low load-factor and it will be noted that Mr. Skinkle states that low-load-factor load is relatively the cheapest power that can be purchased."

In rebuttal of this point, attention is called to Fig. 8, where it will be seen that of the $28,000 a month constant cost, $20,000 represents fixed charges on the investment. If the station is already built, the investment is "frozen" and can not be liquefied; therefore, this $20,000 a month can not be avoided. Further, if the station has been in service a long while and has been completely depreciated and written off the books (as is the case in the incident cited), the expense of $20,000 a month has ceased and is no longer an item in the costs.

In either of these cases, it then becomes a matter of comparing "operating" costs with the cost of purchased power rather than basing the comparison on "total costs" which include the item of fixed charges. Therefore, if we now refer back to Fig. 9 and add another line of "operating costs" only, to this figure, this line will start at $8000 a month "constant cost" sloping upward exactly parallel to the "total cost" line for the isolated station. It will be seen at once that for an *existing station* when only the operating costs are considered, they are lower than the cost of purchased power; and, for low-load-factor energy, they are likely to remain so almost regardless of how high the "increment" cost of the old station may be or how inefficiently it is operated. This point nicely illustrates a special case where the engineer is justified in disregarding fixed charges when comparing the cost of generated power with the cost of purchased public utility energy.

At the end of his discussion, Mr. Stoltz suggests that the public utility companies can carry spare equipment more cheaply than the private consumer, and that this might offer an economic solution to the problem. In reply, the author would say, "Try to get it." There are several items against this which may be summed up about as follows:

1. In almost every case except in the most crowded manufacturing districts, the utility company would have to make line extensions of greater or less length. This costs money.

2. In practically every case, an investment in a substation would have to be made. This costs more money.

3. Regardless of the load, there would be considerable expense and maintenance on the line and substation, and in maintaining an open account on the books. This costs still more money.

4. In proposing such a service, the power company would be encouraging prospective customers to maintain their old power-stations, thereby deliberately minimizing the field of the power company's own activities and reducing the company's own market.

5. There would be danger of overloading either a branch circuit or a whole power system with such a mass of what might be called "stand-by service," that might, in case of strikes or similar emergencies, be called for simultaneously. Such a condition could easily require major investments on the part of the power company to bolster up the system in order to avoid serious embarrassment to regular users of the service.

The question is, who is going to pay for all these expenses? The customers of utility companies who do not thoroughly understand power company problems, do enough "kicking" at present, and the power companies are unwilling to add to their service any more intangible costs that will open the way for further complaints.

In three cases, the author has made counter propositions to utility companies, offering to pay utility companies an amount equal to the fixed charges on proposed additions to existing power houses in exchange for stand-by service. While the idea was given serious consideration, the original offer would never be recognized as a basis for the final proposition and the negotiations just died from their own weight.

The discussion of such problems as these has, however, been extremely valuable, as it has afforded an opportunity for each side to examine the problems of the other and, due to the consequent better understanding of the other fellow's problem, a better feeling is rapidly growing between the parties, and a tendency to co-operate is gaining headway every day.

E. D. Dreyfus:* The subject of power rates is a very large one and the author has very wisely selected one feature of the problem that deserves close attention—one that applies to conservation of our power resources and, correspondingly, capital resources.

The complete manner in which the author has handled the problems dealing with the economical use of facilities, leaves little to be said. However, there are some collateral matters I would like to touch upon in a general way.

By examining the trend in the use of power in this country and the rapidly increasing extent to which the needs are being supplied by the electric utilities, the importance of Mr. Skinkle's paper becomes the more manifest.

The excellent presentation of certain features embodied in most rate schedules will undoubtedly prove a boon to both the consumer and the producer of power. Frequently the consumer has a mistaken idea of the producer's position and, conversely, the producer may not always work in the most effective way if he does not properly understand the consumer's problem. The focusing of attention upon these matters, therefore, constitutes a progressive step.

I have been greatly impressed by two features in particular which are often matters of controversy; namely, demand and minimum charges which correspond to no-load costs. Some power consumers feel that they are being imposed upon when they are required to pay a demand or minimum charge, taking the standpoint that they must pay for something they do not get. This is a time-worn argument, but continually cropping up. The trouble seems to lie in the fact that the purchaser does not make the proper distinction in his own mind between (1) "commodities" which he buys when and as needed at virtually fixed prices, but subject to storage, a wide market situation, and delay in delivery, and (2) a "service" which can not be stored, or diverted to other markets, and which at the same time is subject to instant delivery. The very nature of the service involves a definitely fixed expense, not only in capital outlay but in a trained organization ready to take care of the consumer's requirements immediately. It involves also the stand-by costs of fuel and supplies. It is fortunate indeed that we have an engineer of the author's standing and experience to emphasize these facts, for attention to this matter should

*Research Engineer, West Penn Power Co., Pittsburgh.

serve to foster sound decisions in such economic problems. Mr. Skinkle's point that the fixed-charge element of costs is so often improperly treated, is germane.

It is to be borne in mind that the central-station costs have a characteristic similar to that shown for the isolated plant; that is, relatively high no-load costs and comparatively low incremental costs. When such fixed charges are avoided by the consumer through the purchase of power, the charges are merely transferred to the central station. Some industries object to the minimum charge, and even at times to the demand element in the rate. Their contentions usually are that a simple form of rate based only upon the energy actually supplied would be sufficient and that the utility company could, during good times, accumulate adequate reserves or surplus to carry it through a depression. With regard to the first item, it would defeat the very purpose of the two-part rate which is to bring about the most efficient use of plant and facilities and thereby make for cheaper power. Many consumers have so arranged operations as to improve their load-factors in such ways as illustrated by the author. They therefore earn attractive rates, and thus secure their power at minimum cost.

It appears that the use of minimum charges by public utilities is often misunderstood, and the contention is often made that complete relief should be granted when no power is taken. In such cases, the fact is overlooked that the power user escapes a very considerable fixed cost when he purchases power. Fig. 11 illustrates the point in the case of a 10,000-kilowatt load. It will be observed that an independent power-plant minimum will be around $20,000, whereas the utility's minimum charge will be $11,000 or less. Furthermore, central stations have a greater investment per dollar of normal earnings than the average industrial plant, and this feature along with the widely scattered nature and other characteristics of its property make it impossible to reduce expenses greatly when operations are curtailed. Industries are in a more fortunate position in this regard and Fig. 12 indicates how the two compare. With the public utility, the ratio of investment per dollar of revenue is in the order of 5 to 1, as a rule, while many of the basic industries have an investment of about one-half of their gross annual business. Again, the raw product with most central stations is coal, the cost of which is ordi-

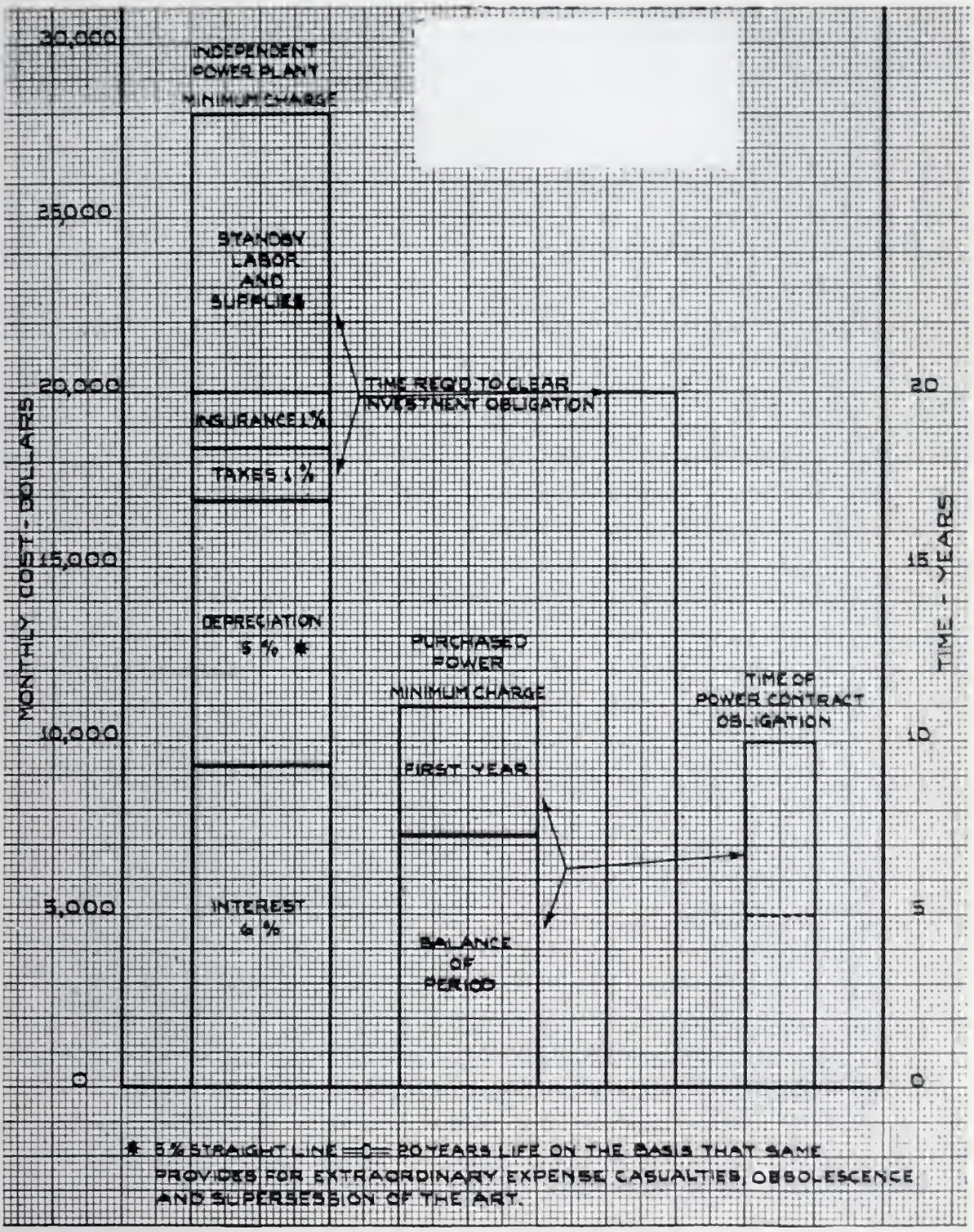

Fig. 11. Indication of Relative Financial Liabilities with Independent Power-Plant and with Purchased Power in Case of Shut-Down.

narily less than 20 per cent. of the total costs, and in curtailing but still preserving the system and the important part of the organization, it is not practicable to reduce more than, say, 30 per cent. of the prevailing costs. On the other hand, raw products and direct labor represent the bulk of the expense in industry and heavy reductions

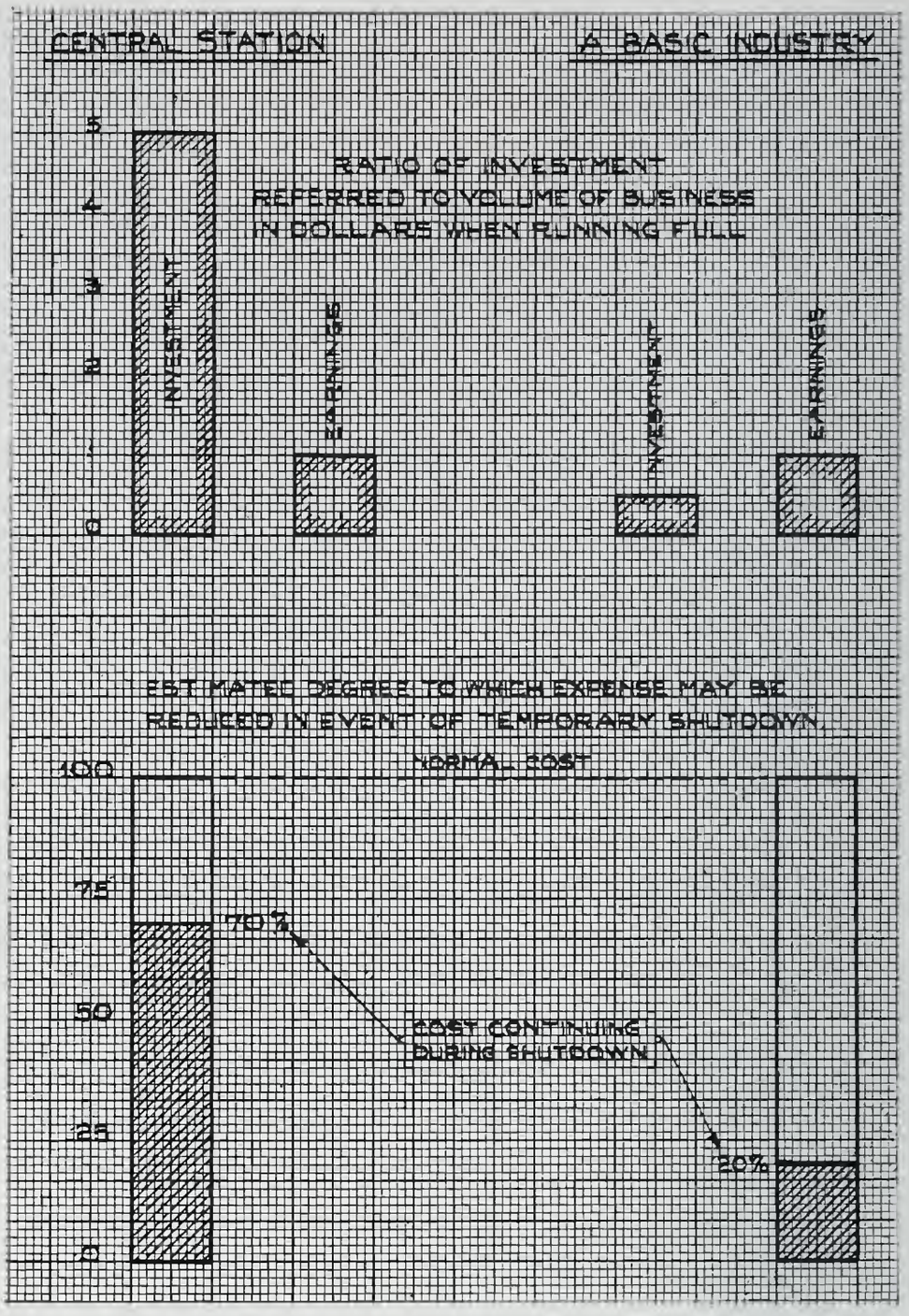

Fig. 12. Indication of Relative Positions of Industries and Central Stations under Average Conditions.

may be effected to an extent of 80 per cent., or possibly more. There is, of course, a wide difference in the fundamental nature of the two kinds of business. Industry enjoys an unlimited market, whereas the public utility is restricted by territory and regulation. When these matters are better understood there will be, undoubtedly, less criticism of this minimum provision of the electric utility.

The charting of the various rate schedules, along with the formulæ developed therefor, typifies the author's analytical approach to

the power problem. The method employed in equating and appraising the wasteful use of peak capacity will undoubtedly be helpful to industry.

A proper demand charge certainly has its place in the economics of power development and should accomplish in a less paternal way the results sought by Gifford Pinchot, when, as Governor of Pennsylvania, he called a conference of representatives of labor, industry, and electric utility to discuss ways and means of rotating the use of time of demand and, therefore, power facilities, and thus conserving capital expenditures which would redound to the benefit of the consumers in the state. While no other action than the exchange of opinion came out of this meeting, it did prove the importance of economizing in the use of power facilities.

A system of rates which properly recognizes this factor will provide the cheapest power in the long run. The development of control equipment to effect close regulation in the use of the demand will also aid in achieving this desideratum.

It is a long process to bring the minds of different people together, and, no doubt, if Mr. Skinkle's paper had been presented years ago, there would have been different courses taken in many cases in the matter of providing for power. Regrettably, we are too often without adequate information by which to gage the result of operating over a long range of time and conditions. Power-plant cost estimates are frequently lower than actual results obtained, as the factor of omission occurs more than that of conversatism.

Mr. Shover has suggested relief for the power user who has created a very large demand at, say, the end of the month, and I might refer to the provision in most power schedules which permits the demand to fall to some fraction of the high demand created during the preceding 11 months, or other period. Possibly, if it were an extraordinary or accidental high peak, some other relief might be afforded in special instances; but I think every one here realizes that if the bars were let down indiscriminately and use was made as will dictated, an excessive burden might be reflected back on the power company. Furthermore, carelessness would probably be encouraged, tending to create a coincident peak at the power-station for which the power company would always have to be prepared, or the quality

of its service would be endangered. The power companies are sometimes regarded as being arbitrary in these matters but under regulation if they relieve in one case they must relieve in all and in such an event it would undoubtedly become very burdensome, so much so that their incomes would be adversely affected and they could not do things now demanded of them and at the same time provide facilities with proper reserves.

ARC WELDING OF STEEL BUILDINGS AND BRIDGES*

By Frank P. McKibben†

INTRODUCTION

The art of welding structural steel by electricity is developing rapidly and this year witnesses many applications of this process to construction of new bridges and buildings, and to reinforcement of existing structures. The electric arc furnishes designing engineers with a new tool which has been widely adopted not only in the fabrication of bridges and buildings, but also in many factories for welding parts of machinery and for assembling structural steel sections as substitutes for castings. With proper supervision of design and workmanship one can secure safe construction, as is evidenced by the existence of over sixty welded buildings in which no failures have occurred. For a new type of construction this is truly a remarkable record; but, in this connection, we must not forget that welded construction in its early stages has received far more experimentation, and more careful supervision in execution, than did concrete or riveted work at the corresponding stages of their development.

Among the most important matters now receiving attention are revision of building codes, preparation of specifications for welded buildings, accumulation of cost data, training of designers, qualification of welders and inspectors, and additional tests of welded joints.

BUILDING CODES

The recent movement to change fiber stresses in steel construction from the 16,000 to the 18,000 pound basis has resulted in the revision of various municipal building codes. Among political divisions now actively engaged in revising their codes are New York, Philadelphia, Pittsburgh, Chicago, Lansing, Schenectady, several cities in California, and the state of California, and it is hoped that in these revisions due consideration will be given to the advantages of welding and that enabling provisions will be incorporated therein.

The American Welding Society's Committee on Building Codes

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is now drafting a code for welding and until the report of this committee is published, cities may either adopt an enabling ordinance without any attempt to specify details of welded steel construction, or may draft codes as complete as is now possible, giving the technique of welding and its application to steel buildings.

An enabling article of general nature is as follows:

"Welding may be substituted for or used in connection with those methods already prescribed in the building code of the City of..... for assembling the component parts of and connecting together various beams, girders, lintels, trusses, columns, or other structural steel used in building construction; provided, that welding be done by competent workmen in accordance with designs and under supervision of a competent architect or engineer skilled in this work; and under regulations or specifications recommended by the Bureau of Building Inspection of the City of..... and adopted by the Common Council of the City of....."

In addition to an enabling article similar to that outlined above, a specific code should include articles pertaining to definitions, materials, apparatus, permissible unit stresses, workmanship, qualifications of welders, proportions of parts, and the protection of steel.

Two points of view exist regarding this matter of codes. On the one hand it is maintained that in the early stages of an art, a municipal code pertaining thereto should be as brief as possible, merely an enabling ordinance without including technique, while on the other hand many architects and engineers claim that a code should be as complete as it is possible to make it. A code is not only for the protection of the public. It is also a set of rules intended to secure fair play among competing designers and contractors, ultimately protecting them as well as the public against evils of extreme competition. I believe the latter is the better way, and by adopting as complete a code as possible, better and safer buildings will result. If responsible engineers, architects, and contractors do not co-operate in this matter to formulate reasonable rules it is probable that in many cases irresponsible parties will produce codes and erect welded buildings of unsatisfactory character—unsatisfactory alike to the owner, the public, and the industry.

The use of welding is extending rapidly and if we desire to guide it along safe channels now is the time for us to act by seeing that codes are revised to permit welding according to proper rules.

SPECIFICATIONS FOR ARC WELDING STEEL BUILDINGS

Architects and engineers are finding that specifications concerning arc welding are not easy to secure, and so many are the inquiries regarding this subject that I take the liberty of presenting here a set of specifications based on experiences gained in welding the frames of four steel buildings, and after conferences with several prominent structural engineers and welding specialists.

Section	*Title*
A.	General Application.
B.	Definitions.
C.	Materials.
D.	Apparatus.
E.	Permissible Unit Stresses.
F.	Workmanship.
G.	Qualifications of Welders.
H.	Proportion of Parts.
I.	Protection of Steel.

SECTION A. GENERAL APPLICATION

A–1. Arc welding may be substituted for or used in connection with rivets or bolts, or other methods prescribed in the Standard Specifications for Structural Steel Buildings adopted by the American Institute of Steel Construction as amended to date, for connecting together, or assembling the component parts of beams, girders, lintels, trusses, columns, or other structural steel used in building construction.

SECTION B. DEFINITIONS

B–1. *Arc Welding.* The process of joining steel parts in the molten or molten and vapor states by the electric arc without the application of mechanical pressure or impact.

B–2. *Arc Weld.* A weld in which welding heat is generated by an electric arc formed between the base metal and the electrode, or between two electrodes, with or without the use of hydrogen or other gases.

B–3. *Electrode.* A specially prepared metal wire or rod used as a terminal in an electric circuit to produce an intense heat by means

of the arc, and which may or may not supply the molten steel required for joining the parts to be welded.

B–4. *Filler Metal.* Metal which is added to a weld by the melting of an electrode or welding rod.

B–5. *Weld Metal.* Material composing a weld.

B–6. *Base Metal.* Material to be welded.

B–7. *Fillet Weld.* A weld, at the intersection of two surfaces approximately at right angles to each other in which the weld metal has a triangular cross-section, two of its sides being fused with the original surfaces of the base metals, and its third side remaining exposed. The size of a fillet weld is expressed in terms of its length and width, the length being the effective length exclusive of crater, and the width being the length of one of the equal sides of the largest isosceles triangle contained in the cross-section of the weld metal.

B–8. *Butt Weld.* A weld joining the edges of a butt-joint in which two members are brought together edge to edge but not necessarily in contact, one surface of each member being in the same plane or in parallel planes.

B–9. *Continuous Weld.* A weld of unbroken continuity used for strength or tightness, or both.

B–10. *Intermittent Weld.* A strength weld consisting of a series of short welds in line, alternating with unwelded spaces.

B–11. *Tack Weld.* A short weld used not for strength, but for purposes of assembling only.

SECTION C. QUALITY OF MATERIALS

C–1. *Structural Steel.* Steel used in structures covered by these specifications shall be of the grade designated as "Structural Steel for Buildings" as specified by American Society for Testing Materials, Serial No. A9 as amended to date.

C–2. *Electrodes and Welding Rods.* Wire used for electrodes or welding rods shall be commercial mild steel wire made for this purpose, of uniform homogeneous physical structure, without irregu-

larities in surface, and free from hardness, segregation, foreign matter, oxids, pipes, seams or other defects.

C–3. Diameter shall not vary more than 0.003 inch above or below nominal values.

C–4. In the hands of an experienced welder electrodes and welding rods shall show good welding qualities in flat, vertical, and overhead positions, and shall pass through the welding process without any unusual behavior.

C–5. Chemical compositions shall conform to the following limits for the uses specified:

	Wire grade A per cent.	Wire grade B per cent.
Carbon	0.13 to 0.18	Not over 0.10
Manganese	0.40 to 0.60	0.25 to 0.45
Phosphorus	Not over 0.045	Not over 0.045
Sulphur	Not over 0.045	Not over 0.045
Silicon	Not over 0.06	Trace

Wire of Grade A shall be used for hand arc welding, and Grade B for automatic machine arc welding.

SECTION D. APPARATUS

D–1. Arc welding apparatus shall be of standard design, and the product of a reputable manufacturer.

D–2. Welding current shall preferably be direct current supplied by generators driven by electric motors or engines having suitable automatic speed regulation. Whether for use in hand or machine welding, generators shall be adjustable for different current values and shall deliver constant current at suitable voltage for each setting of the regulator.

SECTION E PERMISSIBLE UNIT STRESSES

E–1. Welded joints shall be proportioned so that combined dead and live loads, and impact, if any, shall not cause the stresses therein to exceed the following amounts in pounds per square inch:

Shear on minimum section of weld metal.....11,300
Tension on minimum section of weld metal.....13,000
Compression on minimum section of weld metal.....15,000

E–2. Maximum fiber stresses due to bending shall not exceed the values prescribed above for tension and compression, respectively.

E–3. Stresses in welded joints due to wind only, and combined stresses due to wind and other loadings, may exceed by 33 1/3 per cent. the values prescribed above, provided the section thus obtained is not less than that obtained if the wind force be neglected.

E–4. In designing welded connections, allowance shall be made for bending stresses due to eccentricity, if any, except that in designing fillet welds no allowance need be made for the bending couple formed by resultant stresses on the two fused sides of the weld.

SECTION F. WORKMANSHIP

F–1. Surfaces to be welded shall be reasonably cleaned, by wire brushing, chipping, or hammering, to remove loose scale, rust, paint, and other foreign matter; except that a thin coat of linseed oil need not be removed before welding.

F–2. Welding operators shall submit evidence of experience in welding structural steel with the kind of welding apparatus to be used on the proposed work, and shall show ability to make flat, vertical, and overhead welds of uniform quality conforming to the requirements of these specifications.

F–3. After being deposited, welds shall be brushed with wire brushes, and shall show uniform sections, smoothness of weld metal, feather-edges without overlaps, freedom from porosity, and freedom from clinkers. Visual inspection at edges and ends of fillets and butt-joint welds shall reveal good fusion with, and penetration into, base metals.

F–4. Arcs for electric welding shall be of proper lengths to produce good welds.

F–5. Regarding current values for hand welding, the following figures are approximations only, intended as a guide to the operator

who shall select the size of electrode and adjust the electric current to produce good homogeneous welds of the above characteristics:

Electrode diameter in inches	Amperes	Corresponding plate thickness in inches
1/16	50–75	Up to 3/16
3/32	75–100	Up to ¼
⅛	100–150	⅛ and over
5/32	150–200	¼ and over
3/16	175–225	⅜ and over
¼	200–250	⅜ and over

The same size of electrode may be used with various thicknesses of plate, but thicker plates require heavier currents.

F–6. Current values for machine welding may exceed those specified above for hand welding but machine welding shall, if required, meet qualifications for welders hereinafter specified under Section G.

F–7. In assembling, and during welding, the component parts of a built-up member shall be held by sufficient clamps or other adequate means to keep parts straight and in close contact.

F–8. In welding, precautions shall be taken to minimize "locked-up" stresses, and distortions due to heat.

F–9. Before welding new steel to old, both shall be freed from paint and other foreign matter, except that a thin coat of linseed oil need not be removed.

SECTION G. QUALIFICATIONS OF WELDERS

G–1. *Butt Welds.* Welders may be required to weld four sample butt-joints each made of two pieces ½ by nine by 12 inches to form a piece about 12 by 18 inches, prepared with double-vee described hereinafter; of these, two sample plates shall be welded in the flat position and two in the vertical position with the joint located vertically. Each sample plate shall be machined to reduce the joint to the thickness of the base metal. From each sample plate, standard two-inch tensile-test specimens shall be made and tested in tension.

The average tensile strength of each group of two sample plates shall not be less than 45,000 pounds per square inch, and the tensile strength of the lowest in each group shall not be less than 40,000 pounds per square inch.

G–2. *Lap Welds.* Welders may be required to weld four sample lap-joints each made of plates ½ by six by eight inches, clamped one on the other with the eight-inch edges lined up but with the six-inch edges offset ½ inch. A full ½-inch fillet shall then be made along one six-inch edge in accordance with the specifications for lap joints. Upon completion of the welds and after cooling, the specimens shall be torn apart and broken by wedging at the unwelded six-inch edges; and the fractured metal of the specimen broken through the weld shall show bright, dense, even-textured, crystalline or fibrous weld metal, irregularly torn and void of iridescent colors; good fusion of weld and base metals, and good penetration into the right-angle corner of the fillet.

G–3. *Fillet Welds.* Welders may be required to weld three sample test specimens, each specimen consisting of two main plates four by one by 12 inches placed in line with their inner ends separated by ½ inch, making the overall length 24½ inches. These plates shall be connected by two splice plates, each three by ¾ by 6½ inches long, symmetrically clamped to the main plates, one above and the other below the two main plates, and each welded in a flat position to each main plate by two triangular fillets ⅜ by 2½ inches with their craters filled. Each of these fillets shall be started at the outer ends of the splice plate and continue 2½ inches along the 6½-inch dimension towards the center, thus leaving a 1½-inch space between the inner ends of the fillets. The specimens shall then be inverted and the four remaining fillets deposited also in the flat position. In depositing the weld metal, the craters shall be filled to the full cross-section of the fillets. The electrodes used shall be 3/16 inch in diameter. These specimens shall be tested in tension to ascertain the longitudinal shearing value of the ⅜-inch fillet welds, and the fractured specimens shall be examined for penetration into, and fusion with, base metals, and for freedom from gas holes or slag inclusions in fillets. The three specimens shall show at least an average ultimate longitudinal stress of 42,000 pounds per square inch and the lowest

in the group shall show at least 38,000 pounds per square inch of the minimum section of the fillet.

SECTION H. PROPORTION OF PARTS

H–1. Plate girders shall preferably be proportioned by their moments of inertia but where the approximate method of flange design is used, the web equivalent may be taken as 1/6 of the web area.

H–2. Web splices shall consist of two plates, one welded on each side of the web.

H–3. Stiffeners may be angles or flat bars, welded to the top and bottom flanges and also to the web by continuous or intermittent welds designed to transmit the stresses. Stiffeners at bearings or other points of concentrated loading shall be fitted to the flanges.

H–4. Connection of component parts of girder flanges to each other, and connection of flanges to webs shall be by continuous or intermittent fillet welds designed to transmit the stresses. Intermittent welds shall be not less than two inches long exclusive of crater, spaced in the clear not exceeding 16 times the thickness of the thinnest piece connected, nor more than four inches in the clear.

H–5. Plug or slot welds may be used to fasten cover plates to each other and to other members.

H–6. Continuous beams and girders designed in accordance with generally accepted engineering principles may be used, provided that welded connections be properly proportioned to resist bending moments to which they are subjected.

H–7. Welded joints supporting non-continuous beams shall be designed with due regard for secondary bending stresses induced by deflections of the beams.

H–8. When the toe of a seat angle supporting a beam is to be welded and is not truly formed, but is rounded due to worn rolls or other causes, either a preliminary fillet shall be deposited to fill the open space, after which the full fillet required in the design shall be deposited, or the rounded edge of the toe shall be sheared square to receive the full fillet required.

H–9. In tension members of trusses, connected by fillet welds, the gross cross-sectional areas shall be considered as resisting the stresses.

H–10. For tension or compression members having symmetrical cross-sections the fillets shall either be arranged symmetrically about the axis of the member, or else proper allowance shall be made for unsymmetrical distribution of stress.

H–11. For members of unsymmetrical cross-section—angles for example—lengths of fillets shall be determined by taking moments about the gravity axis of the member.

H–12. Built-up or rolled-steel columns shall contain no material, except filler plates (whether in the body of the column or used as lattice-bars or stay plates), less than ¼ inch in thickness.

H–13. Ends of columns shall be faced to plane surfaces at right angles to their axes. Column splices, whenever practicable, shall consist of splice plates connected to the columns with proper amounts of fillets, and if filler plates are required they shall be connected with proper amounts of fillets. When sections of columns to be spliced are such that splice plates can not be used, connections may be formed of plates and angles or other shapes designed to distribute the stresses properly. In all cases, column splices shall be so arranged that, by bolts or otherwise, the various tiers of a column can be accurately alined before welding, and shall be of sufficient strength to carry erection stresses.

H–14. Fillets connecting component parts of a built-up column shall be either continuous throughout the length of the column, or intermittent, arranged with continuous fillets extending at each end of the column for a distance equal to at least the width of the column, then intermittent fillets two inches long spaced not exceeding four inches in the clear for the remainder of the length of the column.

H–15. Lattice-bars and tie-plates, where used, shall be welded with fillets to secure strengths equal to those of the rivets in lattice-bars and tie-plates connected by rivets as specified in Standard Specifications for Structural Steel for Buildings adopted by the American Institute of Steel Construction as amended to date.

H–16. For welded structures, connections of main members carrying live loads producing impact, and connections of members subject to alternate stresses, shall be welded.

H–17. For welded structures, component parts of all columns, girders, and trusses shall be welded with fillet welds.

H–18. For welded buildings more than four stories high, all column splices, and all connections of beams and girders to columns, or within three feet thereof, shall be welded.

H–19. Unfinished bolts may be used in the shop or field for connections of small structures used for shelters; and for connections of secondary members of all structures, such as purlins, girts, door and window framing, lining up bracing, and filling-in beams in floors. In buildings two or more stories high, enough bolts shall be used to connect properly all members during erection.

H–20. So far as possible, all joints shall be designed to eliminate overhead welding, and so arranged that the welds shall be in shear or direct compression.

H–21. Tension butt welds shall not be used in main truss members, but may be used in secondary members, wind-bracing connections, and beam and girder connections.

H–22. To the calculated length of each weld ½ inch shall be added to allow for the crater.

H–23. Fillet welds of lengths less than four times their width shall not be figured as part of any connection.

H–24. The edges of base metal of members ¼ inch or more in thickness, transmitting stress by means of butt-joints shall be beveled with either single-vee or double-vee joints, or their equivalents.

H–25. Steel for single-vee shall be beveled not less than 30 degrees on each edge to form an open angle of not less than 60 degrees, and the joint shall be backed up in an approved manner.

H–26. Steel for double-vee joints shall be beveled not less than 37½ degrees on each side of each piece to form open angles of not less than 75 degrees.

H–27. In all single-vee and double-vee butt-joints the beveled edges shall have initial free distances of 1/8 to 3/16 inch. Steel 1/4 to 7/16 inch thick shall be welded in one layer; steel 1/2 to 11/16 inch, in two layers; and steel 3/4 to one inch, in three layers.

H–28. All the above butt-joints shall be somewhat reinforced but not to exceed 20 per cent. for single-vee or 15 per cent. for each side of double-vee joints.

H–29. All lap-joints in 1/4 to 7/16-inch steel shall be fillet welded in one layer; 1/2 to 11/16 inch, in two layers; and 3/4 to one inch, in three layers. The contour of the cross-section of the fillet shall be an isosceles triangle in which the smaller of the welded sides shall not be less than prescribed for the fillet.

H–30. Weld metal deposited in two or more layers shall have each layer brushed with a wire brush or otherwise cleaned before a subsequent layer is deposited.

H–31. Drawings shall show clearly all welds, including the length and width of all fillets both for shop and field weldings.

SECTION I. PROTECTION OF STEEL

I–1. Structural steel shall not be painted before being welded. If it is to be welded in the fabricating shop only, and subsequently erected by bolts or rivets it shall receive in the shop one coat of acceptable metal protection after shop welding is finished, and one coat after erection. Steel to be welded in the field shall receive one coat of linseed oil after shop welding is completed; and, after being erected and welded, it shall receive two coats of acceptable metal protection.

I–2. No paint shall be applied to steel surfaces which are to be incased in concrete.

ALTERNATIVE BIDS

Judging from the welded trusses of Building No. 1 of the General Electric Company's West Philadelphia plant, the cost of welded trusses should be below that of any other method of connecting truss members. In that case a very great reduction was found in weight of welded trusses as compared with riveted trusses designed to per-

form the same function. A welded truss 58 feet six inches long weighed 5000 pounds as compared with 6800 pounds for a riveted truss—a saving of 1800 pounds, or 36 per cent. of the welded truss. A 78-foot welded truss weighed 9200 pounds as compared with 13,200 pounds for a riveted truss—a saving of 4000 pounds, or 43 per cent. of the welded truss. While in buildings with a large number of trusses a saving is effected by welding, I doubt if very great reductions in cost result at present from the use of welding in buildings consisting entirely of beams and columns; but, where a large number of plate-girders are used in a structure, the probabilities are that welding will materially lessen costs, especially where automatic machine welding is applicable. Be this as it may, the architect or engineer has at his command a very good method of ascertaining whether he can reduce costs with welding. All that is necessary is to ask for alternative bids between riveted steel and welded steel, a method recently adopted in several instances.

QUALIFICATIONS OF WELDERS

On important work on buildings or bridges it is not sufficient to employ welders upon their claims of experience in welding. While their claims may be perfectly correct and made in good faith, it is, nevertheless, true that a welder may be capable of securing excellent results on one class of work and yet be unable to perform well the work at hand. Each man should be tested by at least one of the three methods above mentioned.

A tendency exists to exaggerate this matter of tests for qualifications of welders. It is certainly desirable to have good welders; but an excess of zeal in this matter is unwise because it tends to create skepticism regarding safety of welds, to increase the cost unnecessarily, to restrict welders by rules not applied to other workmen such as riveters and mixers of concrete, and to create unnecessary municipal regulatory bureaus. It has been suggested recently that all welders in a certain city be licensed by the municipal bureau of building inspection. I hope this method will not be adopted in any city. All that is needed is that the engineer or architect in charge have on the work a competent inspector who qualifies the welders by any or all of the methods set forth above. If some municipal regulation is necessary it would seem better to have the contractor for the steel

submit evidence that the welders he proposes to use on the building in question meet the qualification tests. From my experience in this matter I think no municipal regulation should be adopted other than those commonly applied by codes to other types of construction.

Of the various methods, the test to determine the longitudinal shearing value is the best but most expensive for ordinary building construction involving trusses, beams, girders, and columns. The test specimen is designed in such a manner that when the 10 inches of fillets reach their ultimate shearing strength the unit tension in main plates and splice plates will not materially exceed the elastic limit. In fairness to the welders they should be given an opportunity, before making the test specimens, of familiarizing themselves with the type of electrode and current density to be employed.

It is desirable to test the welders in this manner from time to time during the progress of the work. The accompanying Table I

TABLE I. TESTS TO DETERMINE VARIATIONS IN WORKMANSHIP OF FIVE SHOP WELDERS

Number of specimen	Welder's number	Length of fillets total inches	Ultimate load pounds	Ultimate per linear inch pounds	Average per linear inch pounds
3A	3	10	132,670	13,267	
3B	3	10	120,700	12,070	12,669
1A	1	10	127,850	12,785	
1B	1	10	120,630	12,063	12,424
2A	2	10	120,570	12,057	
2B	2	10	113,930	11,393	11,725
4A	4	10	115,510	11,551	
4B	4	10	111,580	11,158	11,355
5A	5	10	105,660	10,566	
5B	5	10	101,370	10,137	10,352
			Average	11,705	

gives the results of such tests for five welders at the Trenton welding shop of the American Bridge Company during the progress of welding the trusses for Building No. 1 of the General Electric Company at West Philadelphia. Regarding the qualifications of these five welders, No. 1 and No. 5 had instruction in a welding school but were inexperienced; No. 2 and No. 4 had practical experience only; and No. 3

had both experience and school instruction. In evaluating the work of these men, longitudinal shearing values are taken as a measure of competency.

Table I shows a maximum ultimate longitudinal shearing stress per linear inch of fillet of 13,267 pounds, and a minimum of 10,137 pounds, with an average of 11,705 pounds. As the minimum shearing section of a ⅜-inch fillet one inch long is 0.266 square inch, the above figures correspond to the following ultimate shearing stresses per square inch of minimum section—maximum 49,900, minimum 38,100, average 44,000 pounds per square inch, respectively. Moreover, when the fillets were stressed to the breaking loads, the average unit tension in the two splice plates (½ by five inches) as well as the main plates (⅞ by six inches) were materially less than the elastic limit in each specimen. It will be noticed that the test specimens used in these tests were slightly different from those given under qualifications of welders in Section G–3.

Table I reveals two interesting facts, though of course it must be remembered that only 10 specimens are included. First, the highest result, 13,267 pounds per linear inch, by the best welder, is 3130 pounds, or 30.8 per cent. above the lowest value of the least efficient welder. The maximum is about 14 per cent. above and the minimum 14 per cent. below the average value. Second, although a considerable variation exists between values of the best and the poorest welders, a conspicuous similarity is shown between the two test results of each individual welder.

INSPECTION

As in riveted steel, and in reinforced concrete construction, the conservative engineer provides inspection of welded work both in shop and field. It is the duty of the inspector to see that sizes and lengths of steel sections are correct, that welders are qualified, that the proper current and electrodes are used, that the current values are changed to suit the various sizes of fillets and thicknesses of steel, that the sizes and lengths of fillets are deposited to conform with those specified on drawings, and that all parts conform to drawings as to size and position. The inspector should be required to make daily reports as to quality and quantity of work performed.

In comparing the lengths of fillets actually deposited in the shop with those designated on the drawings, it has been my experience

that generally the total measured deposits exceed the total computed from drawings, but now and then an individual fillet may be either greater or less than designated. For example, at the welding shop of the American Bridge Company at Trenton the total fillets on one welded truss aggregated 633 1/3 linear inches as compared with 598 inches specified. And while the maximum excess of actual length of an individual deposit over that specified reached as much as 52 per cent., in two other fillets, there were deficits of 8.8 per cent. and 10 per cent., respectively. These deficits are not due exclusively to the welder but sometimes may be attributed to defective drawings on which fillets are shown in places inaccessible for welding.

TESTS OF WELDED JOINTS

Although sufficient test data pertaining to the strength of welded joints are available to enable engineers to produce safe designs for ordinary joints, there is still need for additional tests covering several types of joints which will be used more freely in buildings and bridges when sufficient design data are obtainable.

Tests may be classified under three divisions:

1. Longitudinal shear on fillets.
2. Transverse shear on fillets, involving also simultaneous tensile or compressive stresses on some planes within the fillets.
3. Tensile and compressive strengths of welds in butt-joints.

1. Longitudinal shearing values of fillets have been sufficiently well established for safe design of ordinary connections, but several important problems in connection with this shear have not been studied sufficiently. These are:

a. Relation between longitudinal shearing strength and the length of fillets. Our knowledge of longitudinal fillets is as complete relatively as it is of the shearing strength of a group of rivets; but the exact distribution of the shear along the fillet has not been determined. Several investigations indicate that the strength per linear inch lessens as the fillet becomes longer. We do not know the laws of distribution of stresses over a group of rivets. For example, in a lap-riveted joint with five rivets in a row parallel to the line of stress, are the stresses on the rivets equal, or does each end rivet in the row

carry more stress than the central rivet? If so, how much more? And so it is with a fillet; the end inch has a different stress from the central inch but how this intensity varies we know not. If we can learn this we will know more about welds than we know about rivets.

b. Relation between longitudinal shearing strength and the size of the fillet. A square inch of weld metal in a ¼-inch fillet may have a given longitudinal shearing strength. Will the strength per square inch of a ½-inch fillet be the same? Several series of tests indicate that the smaller the fillet the greater the strength per unit of area, while others do not show this characteristic.

c. Relation between longitudinal shearing strength and the number of layers used in depositing the fillet. Here again there is conflicting evidence, because some tests seem to indicate that the unit strength for a fillet of given cross-section increases if the fillet be deposited in two layers instead of one, while other tests fail to substantiate this.

2. Transverse shear, involving also simultaneous tensile or compressive stresses on some planes exists in a fillet such as that across the top flange of an I-beam welded to the side of a column. If the top of the beam is in tension, the fillet is subjected to a transverse stress which apparently varies from pure shear on the horizontal side of the fillet to pure tension on the vertical side thereof. I say apparently, because the exact location of planes of principal stresses needs study.

3. Tensile and compressive strengths of welds in butt-joints have been given a great deal of attention. The former is useful in designing joints in pipes and cylindrical tanks, while the latter is of value in planning joints such as butt splices in some compression members such as at top-chord splices. Many tests are added daily to the very considerable amount of available information of this nature.

TESTS TO DETERMINE THE LONGITUDINAL SHEARING STRENGTH OF FILLETS

In May 1927, the General Electric Company made and tested at Rensselaer Polytechnic Institute a series of 48 welded specimens to ascertain the longitudinal shearing strength of fillet welds. The results are given in Tables II and III, and summarized in Table IV.

TABLE II. LONGITUDINAL SHEARING STRENGTH OF FILLETS. SPECIMENS TESTED IN TENSION

Specimen number	Fillets: Length inches	Fillets: Linear inches each side		Ultimate load pounds: Total	Ultimate load pounds: Per linear inch of fillet
3/8 inch					
1T–1	3	12		173,300	14,442
1T–2	3	12		164,100	13,675
1T–3	8	12		154,400	12,867
			Average	163,933	13,661
2T–1	4	16		212,000	13,255
2T–2	4	16		216,100	13,506
2T–3	4	16		191,600	11,975
			Average	206,593	12,912
3T–1	5	20		276,580	13,829
3T–2	5	20		268,300	13,415
3T–3	5	20		262,100	13,105
			Average	268,993	13,450
4T–1	6	24		317,000	13,208
4T–2	6	24		316,900	13,204
4T–3	6	24		330,300	13,763
			Average	321,400	13,392
1/4 inch					
5T–1	3	12		139,500	11,625
5T–2	3	12		131,200	10,933
5T–3	3	12		122,300	10,192
			Average	131,000	10,917
6T–1	4	16		176,740	11,046
6T–2	4	16		163,420	10,214
6T–3	4	16		164,860	10,304
			Average	168,340	10,521
7T–1	5	20		232,300	11,615
7T–2	5	20		227,620	11,381
7T–3	5	20		226,560	11,328
			Average	228,827	11,441
8T–1	6	26		257,720	10,738
8T–2	6	24		262,100	10,921
8T–3	6	24		251,800	10,492
			Average	257,207	10,717

TABLE III. LONGITUDINAL SHEARING STRNGTH OF FILLETS. SPECIMENS TESTED IN COMPRESSION

Specimen number	Fillets: Length inches	Fillets: Linear inches each side		Ultimate load pounds: Total	Ultimate load pounds: Per linear inch of fillet
⅜ inch					
1C–1	3	12		185,000	15,417
1C–2	3	12		190,100	15,842
1C–3	3	12		212,300	17,692
			Average	195,800	16,317
2C–1	4	16		268,700	16,793
2C–2	4	16		259,600	16,225
2C–3	4	16		263,100	16,444
			Average	263,800	16,487
3C–1	5	20		318,300	15,915
3C–2	5	20		319,500	15,975
3C–3	5	20		310,200	15,510
			Average	316,000	15,797
4C–1	6	24		391,700	16,321
4C–2	6	24		370,400	15,433
4C–3	6	24		383,000	15,958
			Average	381,700	15,904
¼ inch					
5C–1	3	12		180,000	15,000
5C–2	3	12		200,000	16,667
5C–3	3	12		182,000	15,167
			Average	187,333	15,611
6C–1	4	16		217,600	13,600
6C–2	4	16		225,700	14,106
6C–3	4	16		226,200	14,138
			Average	223,167	13,948
7C–1	5	20		251,700	12,585
7C–2	5	20		231,000	11,550
7C–3	5	20		250,600	12,530
			Average	244,433	12,222
8C–1	6	24		302,700	12,613
8C–2	6	24		332,900	13,871
8C–3	6	24		296,300	12,346
			Average	310,633	12,943

TABLE IV. SUMMARY OF TABLES II AND III, GIVING ULTIMATE LONGITUDINAL SHEARING STRENGTH IN POUNDS PER LINEAR INCH OF FILLET

Specimens tested in tension			Specimens tested in compression		
Length inches	Fillets ¼ inch	Fillets ⅜ inch	Length inches	Fillets ¼ inch	Fillets ⅜ inch
3	10,917	13,661	3	15,611	16,317
4	10,521	12,912	4	13,948	16,487
5	11,441	13,450	5	12,222	15,797
6	10,717	13,392	6	12,943	15,904
Average	10,899	13,354	Average	13,681	16,126

These two series of tests were designed to give ultimate longitudinal shearing values of ¼-inch and ⅜-inch fillets with triangular cross-sections, without stressing the main and splice plates to the elastic limit. Half of the specimens were tested in tension and half in compression, the latter specimens being shorter than the former. All welding was performed by one operator, who did the work by hand, with current of 200 amperes, 3/16-inch electrode, and an arc voltage of 20.

Examination of Table IV indicates that shearing values as determined on the tensile pieces are lower than those given by the compressive pieces. For example, 10,899 and 13,681 pounds per linear inch, respectively, for ¼-inch fillets, the difference being 2782 pounds, or 26 per cent. of the tensile average; while for ⅜-inch fillets the corresponding values are 13,354 and 16,126—a difference of 2772 pounds, or 21 per cent. of the tensile average. The results in general seem to establish no relation between unit shearing strengths and lengths of the fillets, although the unit values of ¼-inch fillets tested in compressive specimens do decrease as the lengths of fillets increase, while others fail to show this trend.

Consider now the ultimate shearing strength per square inch of the ⅜-inch fillets as determined by the tensile specimens. For a ⅜-inch triangular fillet one inch in length, the net shearing area is 0.266 square inch, which divided into 13,354 pounds (Table IV) gives a unit shearing stress of 50,200 pounds per square inch on the minimum section, commonly called the throat; that is, the section passing through the apex of the fillet's cross-section and perpendicular to its hypotenuse.

The longitudinal shearing value of 3000 pounds per linear inch of a 3/8-inch fillet has been quite commonly used in designing welded joints of buildings. In the light of the tests herewith presented let us examine this working unit. Considering for a moment the ultimate values for 3/8-inch fillets as determined by tensile specimens, it is seen that the lowest in Table II is 11,975 pounds per linear inch for specimen 2 T-3, and that is the only value below 12,000 pounds per linear inch. The unit working stress of 3000 pounds per linear inch has, therefore, a factor of safety of four. If we consider the average of all the tests on tensile specimens (13,354 pounds, Table IV), the 3000 gives a factor of safety of 4.4. Obviously, the factor of safety for the shearing values based on compression tests is much greater than that just determined.

This commonly accepted safe permissible value of 3000 pounds longitudinal shearing strength per linear inch for 3/8-inch fillets, divided by 0.266 (the throat distance) gives 11,300 shearing stress in pounds per square inch.

BUILDINGS IN WHICH ARC WELDING WAS USED

During the past year the General Electric Company has completed a building in West Philadelphia, Pa., one in Bridgeport, Conn., and one in Pittsfield, Mass., in all of which the steel is connected principally by arc welding.

The West Philadelphia building (Fig. 1) consists of a head house 78 feet wide by 171 feet long with a vertical clearance of 43 feet below bottom chords of trusses of one aisle 59 by 474 feet, and of a second aisle 79 by 474 feet. These aisles and the head house comprise a building approximately 138 by 552 feet. Supporting the roof over these various parts are trusses of the Pratt type with horizontal chords in the two main aisles, and with a sloping top chord in the head house. Each chord is an eight-inch H-section with horizontal web, while each diagonal consists generally of two small channels with their backs lying in contact with, and on the outside of, the vertical flanges of the H-chords to which the channels are welded by fillet welds. Ordinarily, each vertical member of each truss is a seven-inch I-beam which fits into the trough of the top and the bottom chords, to the vertical flanges of which it is welded. These

direct connections of web members to chords obviated the use of gusset plates at truss joints.

In any building consisting of a main aisle and a transept, especially where there is a traveling crane in the latter, the truss at the intersection of the transept and the head house is somewhat difficult to arrange. In this building, a truss 17½ feet deep spans the main aisle, supports a portion of the roof load, the clearstory, a roof truss in the head house, and a head-house runway girder spanning the

Fig. 1. Arc-Welded Trusses. Building at West Philadelphia, Pa.

59-foot aisle. On account of its depth, this truss was shipped in parts, assembled lying flat on the ground, welded, and erected. All other trusses were completely welded in the shop, and, after erection with sufficient bolts to hold them in position, were welded to the supporting columns.

This building has, in addition to 10-ton bridge cranes in the head house and in the 59-foot main aisle, several smaller bridge and wall cranes.

The Bridgeport building code is a flexible one in that it authorizes the Building Commission to permit the use of new materials if after investigation the Commission is satisfied that the new type is safe and satisfactory. After a study of tests of welded joints, the Commission granted a permit for the General Electric Company's welded-steel building which connects two existing buildings.

This building is a one-story structure with roof trusses of 62-foot span supported on side-wall columns. The interesting details here are the use of tee-shaped top and bottom chords, the truss end bearings at the tops of the columns, and the splice at the center of the top chord. By cutting the web of an H-section along its center thus forming two tees for chords to which web members are welded directly, all gusset plates were eliminated. Beams can be cut in this manner either by cutting with the oxy-acetylene flame or by punching. At the bearing of the vertical web of this top chord tee on the base plate, which in turn rests on the column cap, stiffener plates are shop welded to the tee web. These details are well illustrated in Fig. 2 and 3.

Fig. 2. Truss Bearing. Building at Bridgeport, Conn.

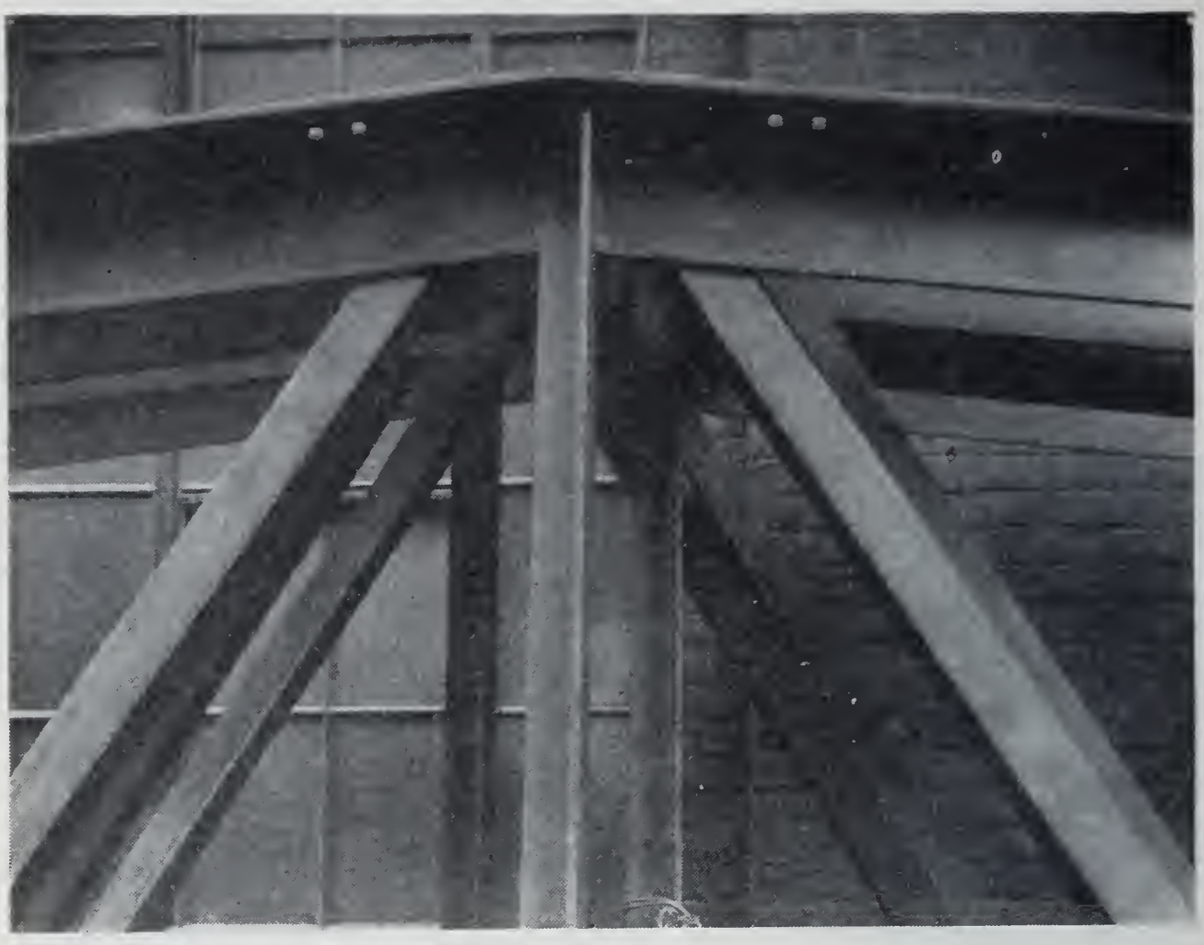

Fig. 3. Splice at Middle of Top Chord. Building at Bridgeport, Conn.

As the roof of this building slopes downward from the center-line towards the ends of the truss, the top chord is given a similar contour, thus necessitating a splice in the top chord at the middle. This is accomplished by a butt splice with a single vee in the horizontal flanges of the tee, while the vertical web is spliced on each side by a leg of a web member connected by fillet welds. As the roof trusses were fabricated completely in the shop by welding, the field welding consisted principally of connecting the top and bottom chords to the columns.

There is a welded factory building at Pittsfield, Mass. This structure is two stories high in part and three stories high elsewhere; length 280 feet; width overall 60 feet; with approximately 40 feet between centers of outside wall columns. The interest here lies entirely in the structural details, among which may be included the following:

1. Connection of a 27-inch main-floor girder to the side-wall column by a shop-welded angle bracket upon which the girder rests,

and by field welding the girder web to the face of the column as well as field welding the top and bottom flanges to the face of the column. The ends of these 27-inch girders were milled.

2. Connection of main 18-inch floor beams to the web of the 27-inch main-floor girders by resting the beams on heavy angle brackets shop welded to girder webs. These seat angles were designed to take the loads to which they were subjected.

3. The use of flat bars as stiffeners welded to the vertical webs at the center of the 27-inch main-floor girders where these rest upon short columns extending from the foundation to the second floor level only. Some details of this building are shown in Fig. 4-6.

Fig. 4. Completed Frame. Building at Pittsfield, Mass.

Fig. 5. Connection of Girder to Column. Building at Pittsfield, Mass.

Fig. 6. Connection of Floor Beam to Girder. Building at Pittsfield, Mass.

All shop and field welding on the above buildings was performed by single-operator, motor-driven generator sets. For depositing 3/8-inch fillets on metal 3/8 inch or more in thickness, 3/16-inch electrodes were used. The current was about 175 amperes, and the arc voltage 20. Current values were less for smaller fillets on thinner steel.

STRUCTURAL STEEL WELDING*

By F. T. Llewellyn†

Two and a half years ago, when the need of an authoritative committee to consider the welding of structural steel was being discussed, a prominent engineer, Mr. J. H. Edwards, who later undertook the chairmanship of the committee, outlined several questions which he thought must precede any general acceptance of fusion welding as a major tool by the structural industry. The questions may be summarized as follows:

1. Can standard grades of steel be satisfactorily welded?
2. What effect will the welding operation have on the base metals that are to be united?
3. Can different processes of welding be standardized?
4. Can values on some unit basis be fixed for the strength of the more usual types of welded joint?
5. Is there some way of determining the reliability of the completed weld?
6. Can the welding operations be performed at a competitive cost?

Since the formulation of these questions, considerable progress has been made in the art of welding. Many commercial structures have been erected by the welding process, involving fairly large tonnages of steel. Much attention has been given to laboratory investigation—microscopic, chemical, and mechanical. There has been more scientific research into the problems of welding within the past few years than had been given to other methods of fabrication throughout their entire period of use. It therefore seems timely to indicate to what extent Mr. Edwards's very pertinent questions are to-day capable of being answered, and that is the purpose of this paper.

The replies attempted are the personal observations of the writer. They may possibly be modified when the final report of the Structural Steel Welding Committee is ready. In supporting some of them material has been borrowed from a remarkably lucid study on metal-

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arc welding by H. Dustin, of the University of Brussels, published in the December, 1926, issue of *Revue Universelle des Mines.** A translation appears in the *Journal of the American Welding Society,* 1928, vol. 7, September, pages 51-71. Professor Dustin's experience is in general agreement with that of investigators in this country.

The facts presented refer primarily to direct-current metal-arc welding. This limitation does not signify that other processes of welding are not suited to structural steelwork. They may, and doubtless would, be entirely adequate, for they have been so found in other fields, but other processes have not been sufficiently developed in the structural field to furnish actual data from which conclusions can be drawn, whereas information as to the behavior of structural members united by the direct-current metal-arc welding process is of considerable extent. This is the process, therefore, that will be generally referred to in the present paper under the brief term "welding."

In view of the fact that much of the information on which our answers are based was secured in connection with the activities of the Structural Steel Welding Committee, already referred to, an outline of the work of this body is in order. The Committee functions under the American Bureau of Welding, a board of research sponsored by the National Research Council and the American Welding Society. It includes representatives from the major engineering societies, the United States Bureau of Standards, the steel-mills, the fabricating shops, and the makers of welding equipment. It was organized in the fall of 1926 for the purpose of obtaining reliable information upon which to base safe unit working stresses in the design of welded structures.

The Committee first studied all available literature giving results of tests on welded joints from which unit working values could be deduced. This information was summarized in the *Journal of the American Welding Society,* 1927, vol. 6, November, pages 8-14. It was found that the information was insufficient to form an authoritative basis for the establishment of standard working stress values. The Committee therefore decided that further tests were needed that would:

*Ser. 7, v. 12, p. 177-206.

a. Confirm or qualify previous results by the use of a larger number of specimens and a more uniform system of testing.

b. Supplement the scope of previous data by tests on additional forms of joint.

c. Determine what degree of uniformity in commercial welding may be expected.

The program now being carried out covers 57 forms of joint in 191 sizes welded by the gas or the arc process. The specimens are of elemental type and embrace fillet welds of lap and tee form, end and edge butt welds, and special joints. Single and double lines of weld —normal, parallel and diagonal to direction of stress, continuous and intermittent—are specified. Entire members may be considered later.

Specimens are to be subjected to static tests for ultimate strength, yield-point, and ductility. These may be supplemented by dynamic and other special tests. The general aim has been to proportion specimens so that they will fail in the joint and thus indicate unit weld strength, but for check purposes there are included a few types that will probably fail in the base metal. In order to determine what degree of uniformity may be expected in commercial practice, multiple specimens of each type and size are scheduled. The preparation of these is being distributed among some 36 representative fabricating shops throughout the United States and Canada. Welding operations will be governed by uniform regulations regarding procedure and inspection. An important part of the program will be the keeping of records as to the sufficiency of these regulations.

About half of the expense is being defrayed by the American Institute of Steel Construction, and the remainder by makers of welding equipment. The steel needed for the specimens, nearly 2000 in number, has been donated by three rolling-mills. Offers to prepare the specimens have been received from a large number of shops, and co-operation in the testing of specimens has been tendered by many laboratories, including that of the United States Bureau of Standards. Special mention should be made of Professor Peter Gillespie, who, under the auspices of the University of Toronto, has made several hundred pilot tests for the guidance of the Committee.*

With this background we will now take up the questions previously presented.

**Journal of the American Welding Society*, v. 8, Mar. 1929, p. 9-27.

1. *Can Standard Grades of Steel be Satisfactorily Welded?* The answer is unqualifiedly in the affirmative. By "standard" is meant those grades of structural steel which are commonly used for bridges or buildings, conforming to specifications A-7 or A-9 of the American Society for Testing Materials. Silicon steel also seems to be well suited to welding, and high-carbon steel and special alloys have been satisfactorily welded, but these products have not been investigated sufficiently to warrant an unqualified statement regarding their behavior when welded. The weldability of standard grades, on the other hand, is established by thousands of tests. Perhaps the best confirmation is the well-known fact that important commercial structures, in every section of the country, framed with members of standard-grade steel, have been and are now being welded with entire satisfaction. (Tables I and II relate to structures erected in 1927-1928.) Certain less satisfactory results reported several years ago, in the welding of thin to very thick metal, have been remedied by directing the arc at the thick metal so as to obtain uniform fusion of both parts.

Closely allied to the matter of grades of base metal steel is that of grades of welding wire. Apparently the latter is the more important. As used in the process we are considering, welding wire plays a dual role. It serves both as electrode and as filler rod. Its use as electrode might connect it with questions 3 and 5, but its use as filler rod makes it more convenient to summarize its functions here. Dustin says that the wire used engraves its indelible signature upon the weld, and that the feature that outweighs everything else is the great importance of a proper selection of welding wire.

The most skillful technique can never make a sound weld if the wire be not sound. The writer will not attempt here to classify the many varieties of wire that are now on the market, but he would go on record to the effect that economy in first cost is an incorrect basis on which to judge welding wire.

The conclusions presented in this paper are predicated on the use of bare wire of a grade equal to classes E 1A (maximum carbon 0.06) or E 1B (carbon 0.13 to 0.18) of the American Welding Society, as applied to mild-steel base metal (maximum carbon 0.30) conforming to specifications A-7 or A-9 of the American Society for Testing Materials. As used here, the word "bare" is comparative, for no wire

TABLE I. WELDED BUILDINGS

Location	Owner	Description	Feet Width	Feet Length	Number of stories	Approximate steel tonnage	Class
Derry, Pa.	Westinghouse Electric & Manufacturing Co.	Factory	164	460	1	350	1
West Philadelphia, Pa.	General Electric Co.	Factory with crane runways	138	552	2	1000	2
Pittsfield, Mass.	General Electric Co.	Factory	39 21	280 280	2 1	250	1
Chicago, Ill.	Mississippi Valley S. S. Co.	Steel warehouse with crane runways	135 clear	340	1	400	2
Emeryville, Cal.	Associated Oil Co.	Automotive shop	60 clear		1	300	2
Hot Springs, Va.	Homestead Hotel	Addition to hotel	72 56	136 56	6 12	550	5
Atlantic City, N. J.	Chalfonte-Haddon Hall	Power house	72	79	6	350	5
North Tonawanda, N. Y.	Tonawanda Power Co.	Office building	74 28	140 32	4 2	200	1
New Haven, Conn.	Yale University	Supports for book stacks	150	220	18	800	5

TABLE II. WELDED BRIDGES

Location	Owner	Description	Spans Number	Spans Length, feet	Total length, feet	Approximate steel tonnage	Class
Leavenworth, Kan.	Chicago & Great Western Railroad Co.	Reinforcement of railroad bridge	3		1100	100	3
Havre de Grace, Md.	State of Maryland	Double decking of highway bridge		250	3300	1500	3
Chicopee Falls, Mass.	Boston & Maine Railroad	Single-track railroad bridge	1	135 skew	170	100	2
Bound Brook, N. J.	Public Service Corporation	Renewal of highway bridge	2	85	170	50	3
Memphis, Tenn.	Harahan Bridge	Widening of roadway				250	3
New York, N. Y.	Interborough Rapid Transit Co.	Girders for crane runway			1800	150	Special

ordinarily employed for welding is absolutely bare. If it were, it would not make a weld. The process of wiredrawing requires a lubricant of lime or some other basic oxid, and enough of this coating is retained on the surface of the finished wire to furnish the slagging flux essential to the soundness of the deposited weld metal. It may be surmised that, if the wiredrawing process had not required such a lubricant, the invention of fusion welding might have been set back many years.

As applied to welding, therefore, the term "bare" refers to wire as it comes from the mill, in contrast with wire that is subsequently given an additional coating or a covering. The term "coated" refers to wire that has received a specially applied fluxing coat (generally a silicate) of considerable amount. The term "covered" refers to wire enveloped by a fabric (frequently of asbestos) which either serves to retain the coating between it and the wire metal core, or which has itself been impregnated with a suitable flux. Dustin states that a coating has three functions:

a. To combine with the oxids of the base metal.

b. To protect the molten or white-hot metal with a deoxidizing slag.

c. To serve as a vehicle for the introduction into the weld of special elements (carbon, nickel, manganese, chromium, etc.) in case it is desired to modify properties. By providing a suitable coating we can actually deposit a steel of any predetermined composition, even stainless or high-speed tool-steel.

2. *What Effect Will the Welding Operation Have on the Base Metals That Are To Be United?* The answer is that it will have no harmful effect—certainly not if the base metal is mild steel. This feature can be presented more clearly with the aid of diagrams drawn to an enlarged scale. Fig. 1 and 2 show ideal sections through fillet and double-vee butt welds, respectively. The contact surface of the

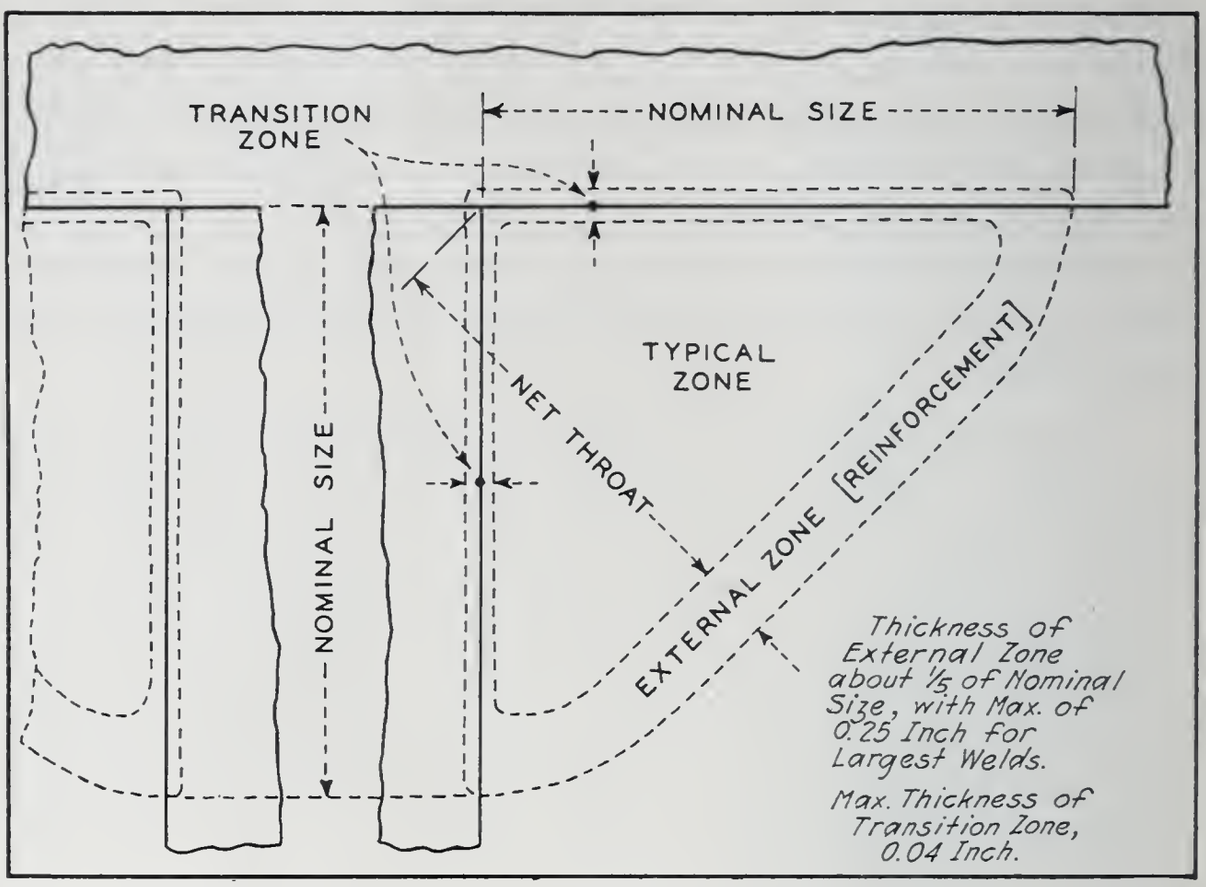

Fig. 1. Sketch of Section through Fillet Weld.

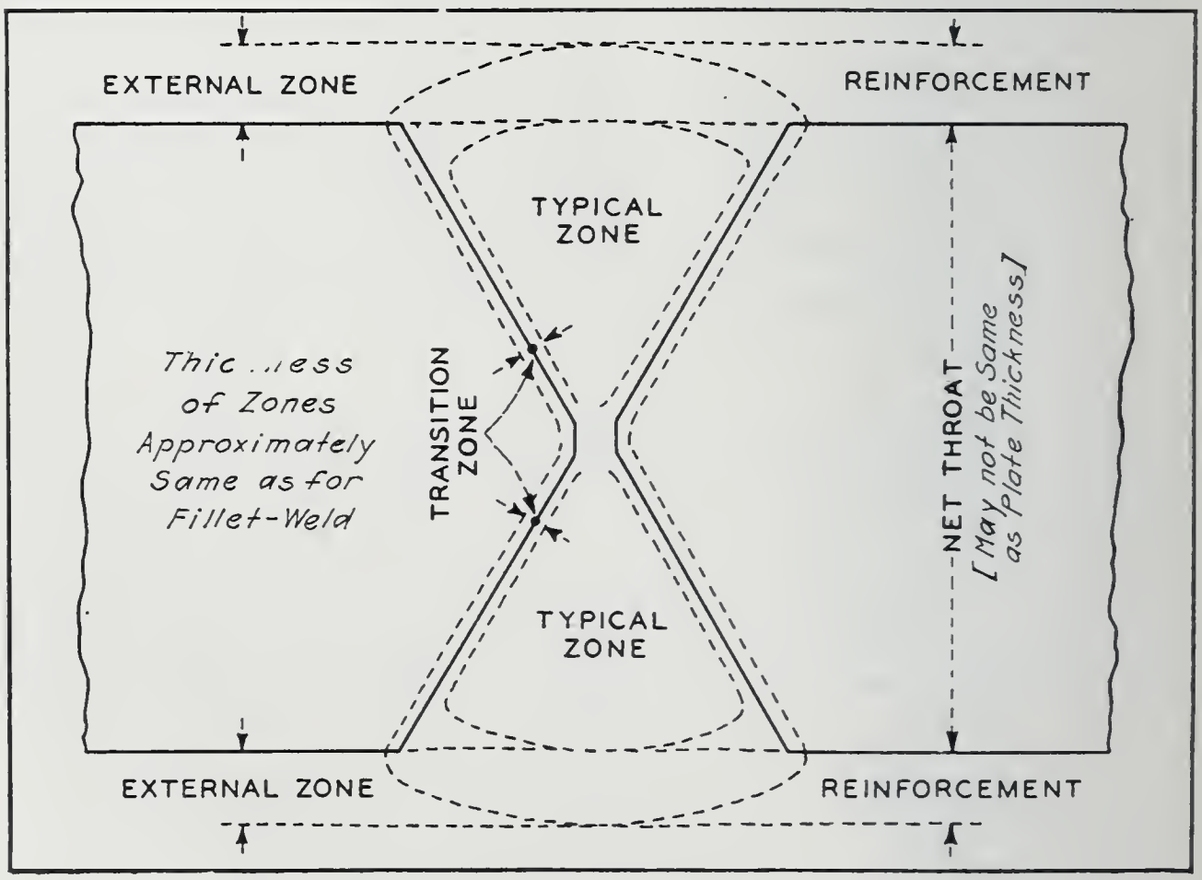

Fig. 2. Sketch of Section through Butt Weld.

original base metal is shown by full lines, and the extent of the weld by broken lines. Referring to the weld as a whole, it has been well said that welding wire normally deposits a soft steel which is purer than its source. Dustin states that if coated mild-steel wire is used the manganese is affected but little, silicon disappears almost completely, phosphorus is somewhat and sulphur greatly reduced, while carbon remains unchanged at from 0.10 to 0.14 per cent. If bare wire is used, the manganese tends to disappear, sulphur may remain, and carbon be reduced to less than 0.05 per cent.

If the base metal is mild steel, regardless of grade of wire or welding conditions, the weld is found to contain three zones, which always occur in the same sequence and with constant characteristics:

a. A transition zone at the contact surface of the weld and the base metal.
b. A typical zone in the body of the weld.
c. An external zone in the outside layer of the weld.

At this time we will consider in detail only the transition zone adjoining the base metal. In extent, this zone never attains a thickness of one millimeter, and only from two to three tenths of its thickness are occupied by the portion in which there is interpenetration of base and weld metal. This zone is sometimes invaded by impurities from the base metal, but no impurity in the weld metal ever penetrates beyond the transition zone into the base metal. These facts are established by many microscopic analyses; therefore any effect of the welding operation on the base metal beyond must be merely a thermal one. We will consider such thermal effect after giving a summary of the characteristics of the transition zone itself. Micrographs show that the transition from base to weld metal is marked by a gradual reduction in grain size—that is to say, by a refining effect—but it is also sometimes accompanied by more slag inclusions than occur in other portions of the weld. In welds properly made, with good wire, these inclusions are too minute to be visible to the naked eye and should not be considered as serious defects. They do mean, however, that the metal in this zone is not always as strong (per unit) as that in the body of the weld, by an amount that never seems to exceed 30 per cent. and is generally very much less. This weaker zone should be, and in current practice is, compensated for

by providing contact surfaces that are greater than the critical throat dimensions. In the case of important butt welds additional area is secured by beveling the edges of the base metal, thereby giving to the weld a vee form. In the case of triangular fillet welds no such preparation is needed, for the reason that the ratio of the leg of an isosceles right triangle to the normal to its hypotenuse is greater than is required. This is one reason why a fillet form of weld is to be preferred in most structural work. It eliminates the cost of beveling.

Reverting now to the thermal effect of the welding operation on the adjacent base metal, it should be pointed out that the heat is conducted across a much narrower belt than is commonly supposed. The writer has frequently touched base metal within four inches of a progressing weld, without any discomfort. While the temperature of the arc is high, its duration at any point is brief; but, whatever the extent of the heat, it is proper to investigate its results.

In tests on welded joints, rupture frequently occurs fairly close to the weld. It would seem as if the effect of welding was to transfer the locus of rupture to a point on the base metal that is at a distance of one or two times its thickness. A hasty conclusion might be that the effect of welding is to cause brittleness in the base metal near the weld. The contrary is indicated by some of Dustin's experiments. He took three merchant steel bars, welded portions of them together, and pulled them in a tension testing machine. All three specimens necked at points straddling the weld, and then broke about half an

TABLE III. EFFECT OF WELD ON BASE METAL

Properties tested	Averages of three specimens machined to 0.79 inch diameter			
	Unwelded			
	Untreated	Annealed 10 minutes at 900 degrees C.	Welded with metal T	Neat weld metal, deposited from wire T
Ultimate tensile strength, in pounds per square inch....	67,200	50,700	53,400	56,700
Per cent. elongation measured on 7.9 inches for unwelded specimens, and on 3.9 inches for neat weld metal	12.0	32.0		16.8

inch away from the weld, under stresses of 53,500, 53,500 and 53,200 pounds per square inch. Their average is tabulated in Table III. Their elongation was not reported. It would be difficult to measure elongation over portions of the base metal sufficiently close to the weld to give significant results. Dustin used other portions of

TABLE IV. SLOW TESTS ON 21 SPECIMENS OF NEAT WELD METAL, DIAMETER 0.39 INCH

Deposited metal	—1000 pounds per square inch— Ultimate tensile strength	Yield-point	Per cent. elongation in 3.9 inches
B	72.5	54.5	20.0
	72.1	50.0	22.7
	71.3	55.0	18.9
	71.1	50.0	24.0
	69.8	49.8	10.0 *a*
	62.6	51.2	7.6 *a*
Averages	69.8	51.3	17.2
T	59.8	46.5	25.0
	58.0	44.1	18.7
	57.0	41.7	14.2
	56.1	39.4	18.5
	56.0	43.9	*b*
	52.7	42.0	7.6 *a*
Averages	56.7	42.4	16.8
N	55.2	43.4	19.3
	56.0	43.0	20.0
	54.3	41.5	*b*
	59.7	28.4	*b*
	51.2	31.3	4.1 *c*
	42.7	34.1	3.0 *c*
	55.5	39.8	16.0 *d*
	54.0	39.8	12.0 *d*
	55.5	38.4	12.0 *d*
Averages	53.8	38.4	12.3

a. No serious defect visible.
b. Broke beyond gage-marks.
c. Serious visible defects.
d. Broke between shoulders, but beyond range of extensometer.

the same bars to make two sets of plain unwelded specimens. One set was tested without any treatment, and the other set was annealed prior to testing. The results are given in Table III, which also shows the average properties of the weld metal used, as tabulated in Table IV.

These tests indicate that the effect of welding was to reduce the ultimate strength of the adjacent base metal by 20 per cent., accompanied however by an increase in ductility as evidenced by the necking. If fabricated by a method requiring punching, the net area of a plate with usual spacing of holes would be reduced still more (33 per cent.), with no increase in ductility.

What happens in the process of welding? The base metal is raised to a bright red color over a belt varying in width with its thickness and with the volume of the weld. It then cools freely in the air. This means that near the weld, the piece undergoes precisely the same treatment as would normalize mild steel. While this indicates that the welding operation has no harmful effect on the base metal, and explains why rupture (in the base metal) is more apt to occur near the weld rather than at a more distant point, it does not explain why rupture is less frequent in the weld itself. The reason is that, while ordinary weld metal has a somewhat lower ultimate strength than the base metal, it has a much higher yield-point (See Table IV). Therefore necking and consequent rupture are apt to start in a normalized part of the base metal rather than in the weld.

3. *Can Different Processes of Welding be Standardized?* The correct answer to this question is, Yes. Specifications covering the making of welds by the direct-current metal-arc process, and by the oxy-acetylene gas process, have already been prepared by the Structural Steel Welding Committee, and are being distributed in printed form (Sections C and D) to the fabricating shops participating in the preparation of specimens. The Committee prefers to postpone any general distribution of these specifications until the conclusion of its major program, when it should be evident whether modification of the requirements is desirable. In addition, a number of representative shops are now engaged in structural welding on a commercial basis, and many of these have prepared for their own use suitable

specifications covering methods of making welds. There is reason to expect that details will also be standardized. Already we are using ⅜-inch fillets as standard in much the same way as ¾-inch rivets have been standard in older methods of fabrication.

An authoritative specification covering methods will doubtless be available to the industry within the next year or two. The demand is apparent.

4. *Can Values on Some Unit Basis be Fixed for the Strength of the More Usual Types of Welded Joint?* To this question the writer would give a qualified answer—for quiescent static loads, Yes; for dynamic loads, Probably. Welded joints subjected to considerable shock require further investigation. Some of the writer's associates in the welding industry may consider the qualification as regards dynamic loads to be unduly conservative, but there is evidence that forms of welded joint, which have a known resistance under static load, can not when merely increased by the usual impact ratio be considered to have the same resistance under shock. It does not follow that welded joints are unsuited to resist shock. Many structures are now in use where they perform this function very efficiently. It is a fact, however, that our knowledge as to their precise behavior under shock is limited, and the need for further study along this line is urgent.

The situation with regard to welded joints subjected to quiescent or static load is entirely different. We have hundreds of tests under this kind of loading with results agreeing with as much uniformity as do those on unfabricated steel, and with more uniformity than many of the tests that have been made on steel fabricated by other methods.

In discussing the properties of welds, it is necessary to distinguish between the strength of the neat deposited metal and the strength of the joint as a whole. Dustin reports a series of tests, made at Brussels, on deposited metal without reference to the members to be joined, using three different brands of coated wire. He does not state whether alternating or direct current was employed. The three brands of wire are here designated respectively by the letters B, T, and N. All of them were of mild steel containing 0.10 to 0.14 carbon.

Wire B was very high grade, but costly. It was electro-plated

with 1.25 per cent. of nickel, and carried a thick coating confined by a braided asbestos covering. It is not representative of grades commonly used in America for structural work, but its results are interesting as showing the high physical properties that can be secured by the use of a suitable wire.

Wire T carried no nickel and had no enveloping fabric. Except for its heavy coating it seems to parallel the better grades of wire that are used in this country for structural work, its carbon being intermediate between our classes E 1A and E 1B.

Wire N was a cheap grade, corresponding apparently to material used here for minor repair work, except that it had a thin coating.

Table V shows the ultimate tensile strength of 105 specimens of three sizes, consisting of neat weld metal deposited by wires B, T,

TABLE V. TESTS ON 105 SPECIMENS OF NEAT WELD METAL

Ultimate tensile strength, in units of 1000 pounds per square inch

Metal B —Diameter, inches—			Metal T —Diameter, inches—			Metal N —Diameter, inches—		
0.39	0.79	0.39	1.18	0.79	1.18	0.39	0.79	1.18
69.8	78.4	71.1	54.1	59.9	58.5	43.4 *a*	42.7 *a*	47.8
69.8	76.9	69.8	42.8 *a*	59.9	60.6	40.6 *a*	37.8 *a*	46.4
74.0	67.6	71.1	39.9 *a*	62.6	60.6	44.1 *a*	36.4 *a*	46.4
72.5	75.5	73.5	44.2 *a*	62.6	64.7	42.7 *a*	46.5	47.8
74.0	66.9	63.8	57.0	57.7	48.3	49.8	49.8	41.3
68.3	71.1	59.1	59.2	60.5	51.2	54.0	52.0	41.2
	73.4	61.2	43.5 *a*	57.0	49.8	44.1 *a*	52.0	40.6
	74.0	68.2	58.4	57.0		49.1	49.8	
	71.1	59.8	57.6	50.5		41.3 *a*	49.8	
	75.5	65.5	64.7	60.5		54.0	49.8	
	62.6	64.0	64.7	53.4		59.8	56.3	
	62.6		59.1	62.6		57.0	54.0	
	66.9		55.5	58.4			54.0	
	76.9			57.0				
	76.9			56.1				
	68.3			57.0				
	75.5			57.0				
				57.0				
				56.6				
Gross averages								
71.3	71.7	66.0	54.0	59.0	56.2	48.4	48.4	44.4
Net averages disregarding 13 specimens *a* with visual defects.			59.0	59.0	56.2	54.0	51.3	44.4

and N. We may approximate their averages at 70,000 pounds for metal B, 56,000 for metal T, and 50,000 for metal N. The uniformity of the results for each metal is very satisfactory. Not less so is the fact that even those specimens that showed small visual defects developed values well above the yield-point of mild rolled steel.

Table IV shows the results of slow tension tests on 21 small specimens. The values for ultimate tension agree fairly well with those of Table V. The yield-points average approximately 51,000 pounds for metal B, 42,000 for metal T, and 38,000 for metal N. The values of elongation definitely reflect the respective qualities of the wires used.

Other tests on metals B and T indicated moduli of elasticity of 29,000,000 pounds under tension, and of 10,500,000 under shear. These are substantially the values for mild rolled steel. They also indicated average ultimate strengths under shear of 48,000 pounds for metal B and 41,000 for metal T, with corresponding yield-points of 27,000 and 22,000 pounds. Dustin's tests for impact and fatigue were not very systematic or conclusive. He warns against the use of any but high grades of wire in structures where much shock is to be withstood, or where there will be alternating repeated stress of considerable amount. Lloyd's rules require a weld subject to fatigue to resist 12,800 pounds per square inch for 5,000,000 cycles. This value is about half the yield-point of sound weld metal deposited by good grades of wire.

In order that working values may be useful they must be expressed in units that can be readily checked in shop or field operations. For butt welds (Fig. 2), the throat area (in square inches) is a suitable criterion. In computing this area the writer recommends that any reinforcement be disregarded, and that the base metal thickness be considered as net throat. For fillet welds (Fig. 1), the throat would also be a proper criterion, but its use is less convenient than is that of the leg, and as the mathematical ratio between them is constant the latter is also correct. In practice, it seems advantageous to express fillet values in terms per linear inch for each size of weld.

The use of gages is recommended in order that the welds as actually made shall conform to theoretical dimensions within reasonable tolerance. Fig. 3 shows a set of five convenient gages, each only 4½ inches long, which can be applied to butt welds of ¼, ⅜, ½,

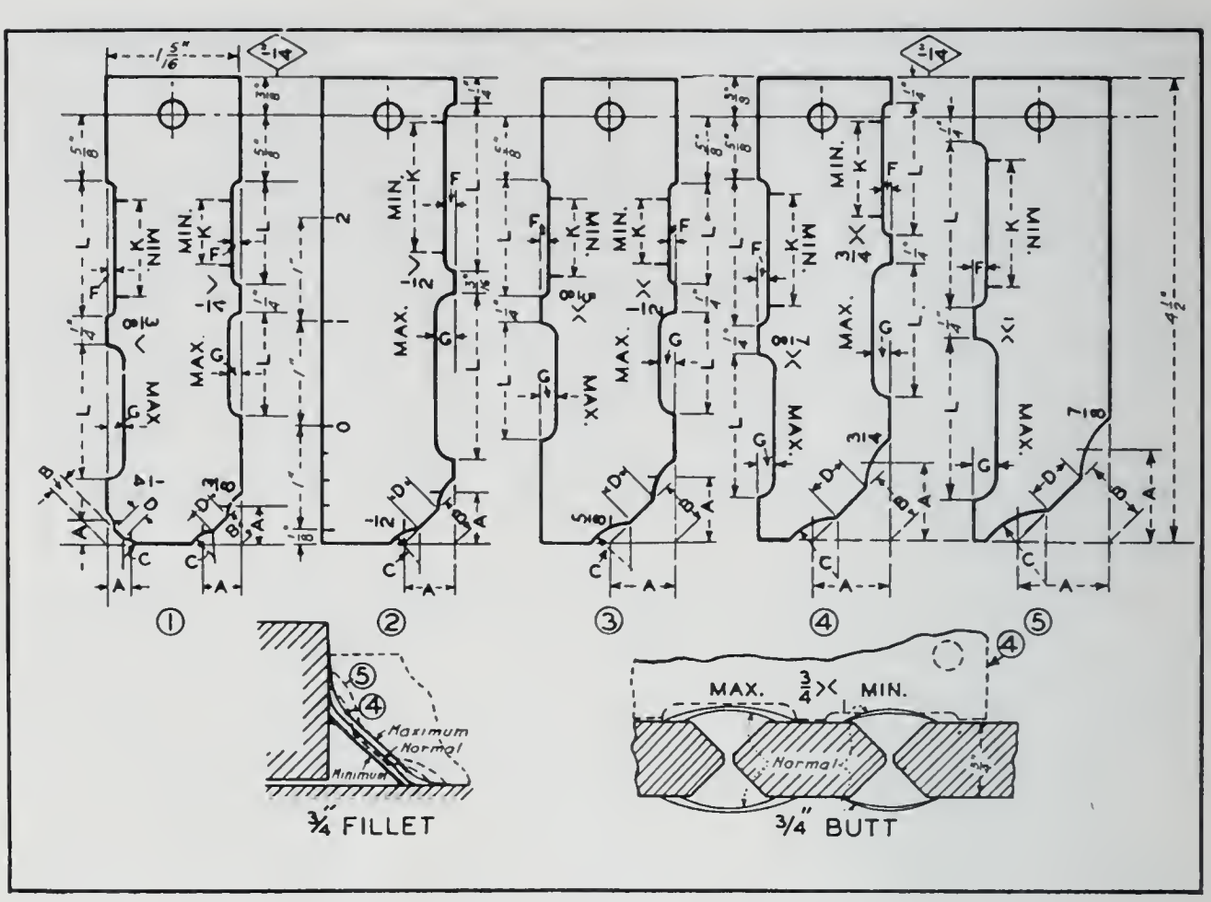

Fig. 3. Method of Applying Gages.

5/8, 3/4, 7/8 and 1 inch; and fillet welds of 1/4, 3/8, 1/2, 5/8, 3/4 and 7/8 inch. The method of application is shown at the bottom of the flange. The limiting dimensions are tabulated in Table VI. These gages have been used commercially by the Newport News Shipbuilding and Drydock Company for some years, and are now being employed in the major program of the Structural Steel Welding Committee. A system for checking the number and location of welds is essential.

Allowable working unit values for fillet welds appear to be crystallizing at about 28 per cent. of the ultimate strength under shear of the neat weld material. This percentage assumes the depth of throat to be the minimum permitted by the gages; thus, a value of 3000 pounds per linear inch is in frequent use for the popular 3/8-inch fillet. Pending the final report of the Committee, this value (under static load) seems to be suitable for properly made welds, and it further looks as if a safe value for other usual sizes of fillet can be figured on the basis of 1000 pounds per eighth of an inch of nominal size.

Values around 15,000 pounds per square inch have been employed for butt welds in tension. The writer is inclined to think

TABLE VI. DIMENSIONS FOR GAGES

Fillet welds

Nominal size A	Throat: Minimum B	Throat: Normal	Radius C	Dimension D
1/4	0.177	0.221	3/16	1/8
3/8	0.265	0.309	1/4	3/16
1/2	0.354	0.398	3/8	1/4
5/8	0.442	0.486	1/2	5/16
3/4	0.530	0.574	5/8	3/8
7/8	0.619	0.663	3/4	7/16

NOTES: Dimension D is symmetrical about 45-degree axis from corner of gage. At no point shall weld fall below triangle of its nominal size, nor exceed triangle of nominal size 1/8 inch greater.

Butt welds, angle between bevels 75 to 90 degrees

Nominal size E	Reinforcement for single-vee weld			Reinforcement for double-vee weld			Width	
Plate thickness	Minimum F	Maximum G	Normal	Minimum F	Maximum G	Normal	Minimum K	Maximum L Arc welds only
1/4	0.063	0.125	3/32				5/8	1
3/8	0.063	0.156	3/32				13/16	1 5/16
1/2	0.094	0.187	1/8				1 1/4	1 5/8
1/2				0.063	0.162	3/32	5/8	1
5/8				0.075	0.175	1/8	25/32	1 1/8
3/4				0.100	0.200	5/32	13/16	1 5/16
7/8				0.050	0.150	3/32	1 3/32	1 7/16
1				0.088	0.187	5/32	1 1/4	1 5/8

that, in the present state of the art, in the case of the comparatively few structural butt welds that are called for, a working value of not over 13,000 pounds per square inch is preferable. In many structures, details can be arranged so as to eliminate all butt welds, and this seems to be desirable whenever it can be done.

In discussing working values, no distinction has been made between large and small welds. Other things being equal, the unit strength of a perfect small weld is measurably greater than that of a large one, and a small weld also requires proportionately less weld metal, but from a practical standpoint this superiority in unit strength is probably counterbalanced by the greater proportional effect of a minor defect in a small weld. Neither has reference been made to the disposition of the line of weld with relation to the direction of stress. In many specimens tested under static loads, welds alined normal to the direction of stress have shown somewhat higher unit

values than have welds alined parallel to the direction of stress. The difference, however, does not seem great enough to warrant different working values. On the other hand, in the case of the few specimens that have been tested under impact, welds alined parallel to the direction of stress have shown higher and very much more regular values than have those at right angles. Behavior of welds under such dynamic conditions is a feature that calls for further study.

It will be noted that, whereas the yield-point of mild rolled steel is usually a little more than half its ultimate strength, the yield-point of weld metal, as shown in Table IV, is from three-fifths to four-fifths its ultimate strength. This means that, with the same factor of safety as referred to ultimate strength, the weld has a considerably higher factor of safety as referred to the more critical yield-point.

In the design of welded structural joints there is a specific feature that should be watched with care. The possibility of any considerable eccentric stress is to be avoided. A designer of the old school will naturally provide for joints that are symmetrical when once the structure is complete. It is equally important to arrive at symmetry in the details of each part. For example, Fig. 4 shows that a fillet

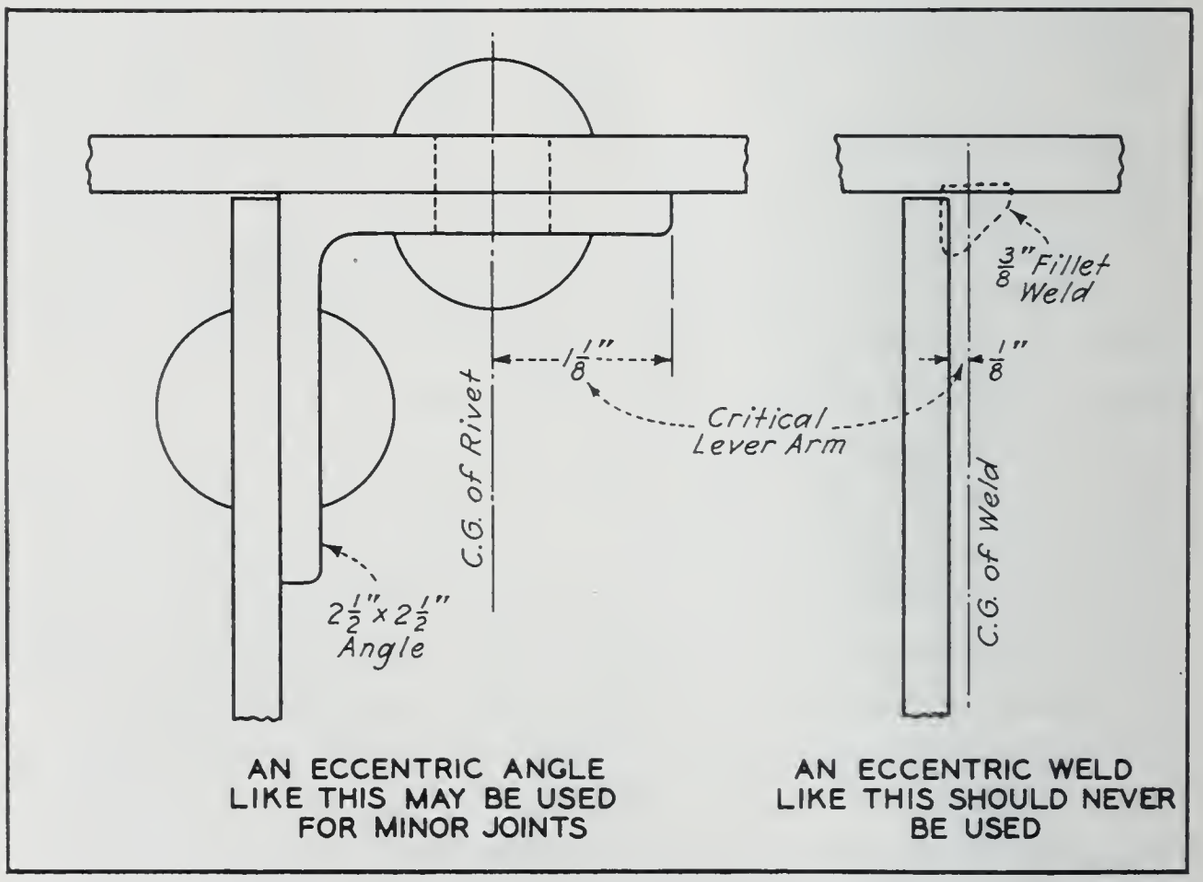

Fig. 4. Comparison of Eccentric Joints.

welded on one side of, say, a minor joint has only one-ninth the lever arm that a single 2½-inch riveted angle would have. With such a weld, the lever arm would offer no appreciable resistance to those prying actions that are apt to occur during handling. It is therefore desirable to weld fillets on both sides of a member, making them short or intermittent if their duty permits.

Perhaps the most convincing proof that unit values for the strength of welded joints can be determined is the fact that such values have been, and are now being, employed commercially in the design of a large number of important structures, with entire satisfaction to all concerned. A year ago Professor McKibben compiled a list of 55 such structures. A few examples of recent welded construction in America are cited in Tables I and II. The classification is explained in our answer to question 6.

5. *Is There Some Way of Determining the Reliability of the Completed Weld?* This is doubtless the most important question to be answered. All the foregoing features are secondary as compared with the question of reliability. Whether a structure be designed with unit stresses of 2000, 2500, or 3000 pounds per linear inch of fillet weld, is of little consequence unless the weld is good. On every hand one is asked, How can we be sure whether a weld is sound? Can we eliminate the human equation? These are natural and proper questions, and nothing is to be gained by avoiding them.

There have been developed a number of methods for investigating reliability in welding, such as visual inspection for shape and color, sound of the arc, X-ray examination, and the electric conductivity test for potential drop. Automatic processes are also finding increased fields of application. All these things are good—visual inspection is especially feasible and significant—but from a rigorous standpoint the writer believes that we can no more be certain that a specific portion of a weld is sound, without destroying it, than we can tell whether a specific rivet fills the hole, without destroying it. Expressed conversely, it is just as possible to determine the reliability of a completed weld as it is possible to determine the reliability of a riveted joint.

We have confidence in rivets, and rightly so—not because the inspector's hammer rings true when applied to their heads (it is well

known that a poorly driven rivet can be given a resonant head), but because we have used them with satisfactory results over a long period. Confidence in rivets has been a thing of growth. Thirty-five years ago all structural specifications limited field rivets to only two-thirds the value allowed for shop rivets. To-day that classification has gone, and the distinction is between hand-driven and machine-driven rivets. We have acquired confidence in the machine-driven rivet. If welding is to be considered seriously as a structural tool, similar confidence in its results must be given opportunity to develop. This may be done in several ways:

a. By familiarity. Let every structural shop do some welding, no matter by what process. If there be any hesitancy regarding major joints then weld the minor ones, but install at least one equipment and use that as a nucleus.

b. By cutting out short sections of weld and examining their interior. They can readily be replaced by the process of welding without detriment to the joint.

c. By occasional non-destructive tests on portions of a completed structure, with loads of, say, 1½ times those for which it was designed.

d. Most important of all, by qualifications of the welder. This is necessary, and fortunately it is feasible. The Structural Steel Welding Committee has prepared a specification for qualifying welders (Section B) with requirements covering what may reasonably be expected in commercial practice. Printed copies are being distributed, and pending the completion of the Committee's final report this document may be considered as a tentative standard representing our best knowledge to-day.

e. By a proper selection of welding wire. The importance of this feature has already been emphasized.

6. *Can the Welding Operations be Performed at a Competitive Cost?* They can for certain classes of work. For other classes of work, costs so far available have been higher than those for older methods of fabrication and assembly. The higher costs appear to be reflected, not so much in the expense of making the welds themselves, as in the labor involved in preparation. In certain kinds of work this labor resulted from the need of cutting rolled steel members to lengths

with closer tolerances than the established practice at the mills. In all cases where material had to pass through a shop, costs were augmented by the fact that, so far, there has not been a sufficient volume of structural welding to keep any shop continuously busy.

With fabricating shops organized along existing lines in which welded jobs are undertaken only occasionally, the following classification of work from an economic standpoint seems to represent our experience:

a. Competitive costs can be secured on low beam-and-column buildings in which the details are sufficiently simple to permit the rolled steel members to be shipped unfabricated from the mill direct to the site, thereby requiring only field welding.

b. Competitive costs can be secured in certain types of shop-welded structures in which considerable savings in weight are obtainable, notably in truss work wherein the net section of tension members is a criterion, and where gusset-plates and other expensive details can be largely eliminated.

c. Competitive costs are frequently obtainable on existing bridges and other structures which require reinforcement to meet added loadings. The saving here is largely due to the expense of hand drilling holes in the field.

d. Competitive costs may not be obtainable on the taller beam-and-column buildings in which details are so important as to require shop preparation, until such time as there is enough business of this character to occupy a shop continuously.

e. There is a class of tall beam-and-column buildings which, from a broader economic standpoint, can be welded advantageously regardless of present costs. This class embraces additions to buildings already occupied, where the elimination of noise during construction has real monetary value. Hotel owners are becoming alive to this feature, and it is also a factor in some other commercial buildings as well as in the case of hospitals and colleges. The saving of space during alterations, and the decreased amount of demolition also make this process economical as applied to the detailed connections of a new to an existing structure.

The American Welding Society is frequently asked for advice by officials who desire to amend city and other building codes so as to provide for welding as a major tool. That Society is endeavoring

to compile authoritative specifications as rapidly as is consistent with safety. Until such specifications are available it is recommended that the welding of structural work be covered by a special permit, with due attention to the responsibility and skill of the applicant.

The writer does not consider that welding is necessarily a competitor of the older methods of fabrication, such as punching. He believes that in many structures the two processes can be combined, with results that will prove more advantageous than if either were used exclusively.

In conclusion, it may be convenient to sum up the answers here attempted:

1. Standard grades of structural steel can be satisfactorily welded. Many special grades seem well suited to welding.

2. The welding operation does not adversely affect standard structural grades of steel. It gives a highly localized normalizing treatment with exactly the same results as accompany the well known process of heat treatment.

3. Methods of making welds by different processes have been standardized to a considerable degree.

4. Unit values for the strength of welded joints can be readily determined. Safe values for the most usual forms of joint, under static load, are already known. Investigation is now going on in the case of other forms under static load. The need for further research as to the behavior of all forms under shock is urgent.

5. The welded resembles the riveted joint in that their absolute soundness is determinable only by destructive test. The practical soundness of a welded joint is readily determined, without destructive test, by the taking of certain precautions, of which the most important are the periodical qualifications of each welder by specific test, and the selection of suitable welding wire.

6. At the present time the economic advantage of welding varies with different classes of work.

DISCUSSION

C. S. Davis, *Chairman*:* A few minutes ago I noticed the entrance of the Chairman of the Structural Steel Welding Committee and without having previously asked his permission I am going to call on him to open this discussion.

J. H. Edwards:† When I came into the room and went to the far corner, I hoped no one would see me. Surely I did not want your Chairman to see me because ever since we were six years of age he has been trying to get even with me. We were brought up in the same little town.

There is not much to say on the subject as Professor McKibben and Mr. Llewellyn have covered it in such a fair and open-minded manner. I am very much gratified to know that after three or four years' connection with the study of welding, it has developed so rapidly and is going along in such a sane, fair way. I will say that at the start there was a chance of its getting on the wrong track, and probably being retarded for a number of years through perhaps some over enthusiastic statements that were being made by people who had commercial interests to promote. Some of you have heard me say that before.

We are on the right track now. We are all co-operating. The people who are developing the technique of welding and the people who are developing the design for the use of welding are in harmony; they are working together, and let us hope that they will continue to co-operate in the development of what promises to be a very valuable tool.

Now, that you have me up here I want to do a little trade talking. You know they wished a job on me in connection with the Structural Steel Welding Committee of the American Bureau of Welding. We need a lot of help. Just at the present time we have a number of shops in line for welding with electric equipment. We have given them all lists of welding samples. We would like to have two or three additional fabricators doing gas welding to help us out. Besides that we would like to have you, who are interested in the subject, and have some sort of contact with testing laboratories, either

*Consulting Engineer, Pittsburgh.

†Chief Engineer, American Bridge Co., New York.

college or commercial, use your good influence to have laboratory testing help given the Committee. This testing of welded specimens is a project which we hope will be of great benefit to the industry. It is not a strictly scientific research problem; it could not be, under the circumstances, but we believe it will prove to be of great practical value and start us along the right track in the way of the adaptation of the welding processes to the fabrication of structural steel.

A. M. Candy:* I almost feel as if I were usurping time to talk on this subject, because it has been covered so thoroughly that anything I might say would seem redundant. But there have been several ideas brought out on which I would like to make a few remarks. In the first place, Professor McKibben has the right idea as to specifying the qualifications of welders in city building codes. If that is carried out along the lines indicated, the whole process of welding, as far as building structures are concerned, will be more or less hampered. That point was brought out at one of the recent meetings of the American Welding Society at Philadelphia last month. The question came up as to the qualifications of welders who will participate in the series of tests that Mr. Edwards mentioned, and then we got to the point of selecting the inspectors who would have supervision of these welding operators in producing these qualification tests to determine whether or not the specimens made by the operators would probably show up well when tested. That brought us to the point of the selection of inspectors and qualifying the inspectors. You can see that we were fast working into a circle to get somebody to qualify the man ahead and we are chasing ourselves around like a kitten chasing its tail. I am afraid that we will defeat the whole purpose. I do not mean that the welder should be allowed to weld promiscuously without proving his ability by some qualifying test.

I would like to touch on the question of confidence in welding. That is a point that a number of us have been preaching for years and I think we have got to the point where a good many engineers do have confidence in welding when it is carried out under proper supervision and with properly designed work. That is what counts,

*Welding Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

after all. We must have confidence and faith in our processes or we shall never get anywhere. It is with that in view that I offer a few illustrations to show you the confidence our company has in arc welding, and to point out some of the work that has been done.

Fig. 5 shows the frame, rocker arm and brush rigging of an entirely arc-welded direct-current machine manufactured in capacities of 100 to 2000 kilowatts, at speeds of 100 to 1000 r.p.m.

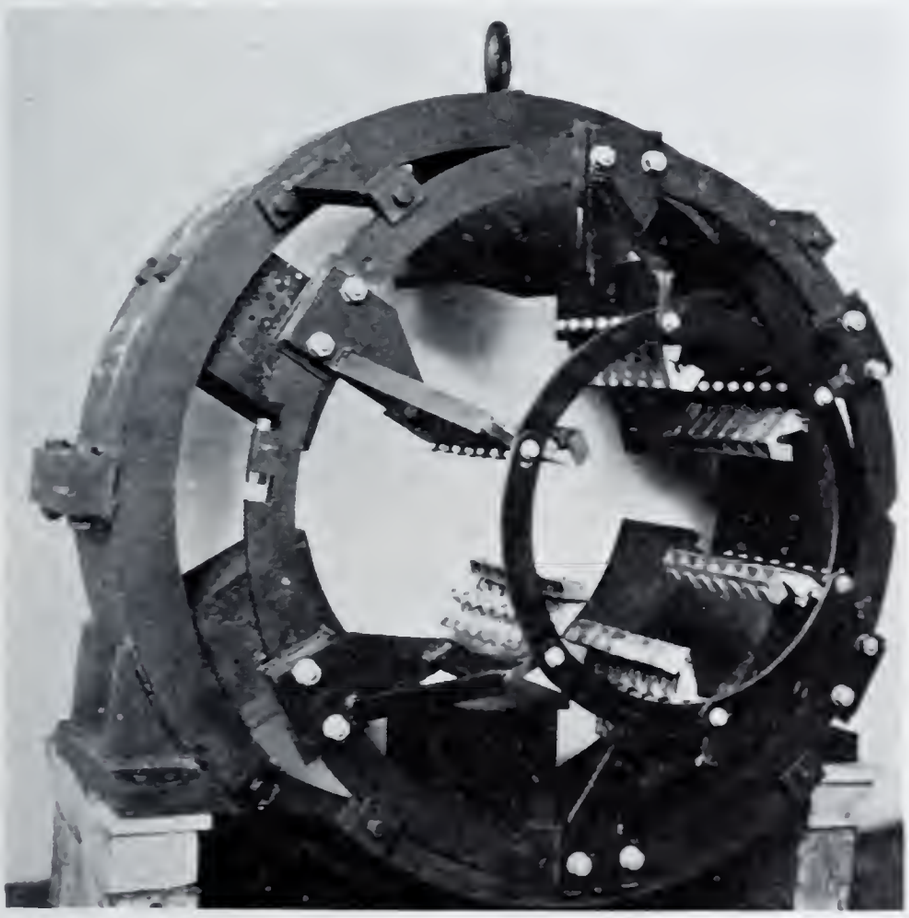

Fig. 5. Arc-Welded Construction.

Fig. 6 illustrates the welded construction of the armature spider and core for the same machine.

Fig. 7 illustrates one of a standard line of synchronous motors having completely welded frames, bases, and rotating elements, made in capacities of 70 to 700 horse-power.

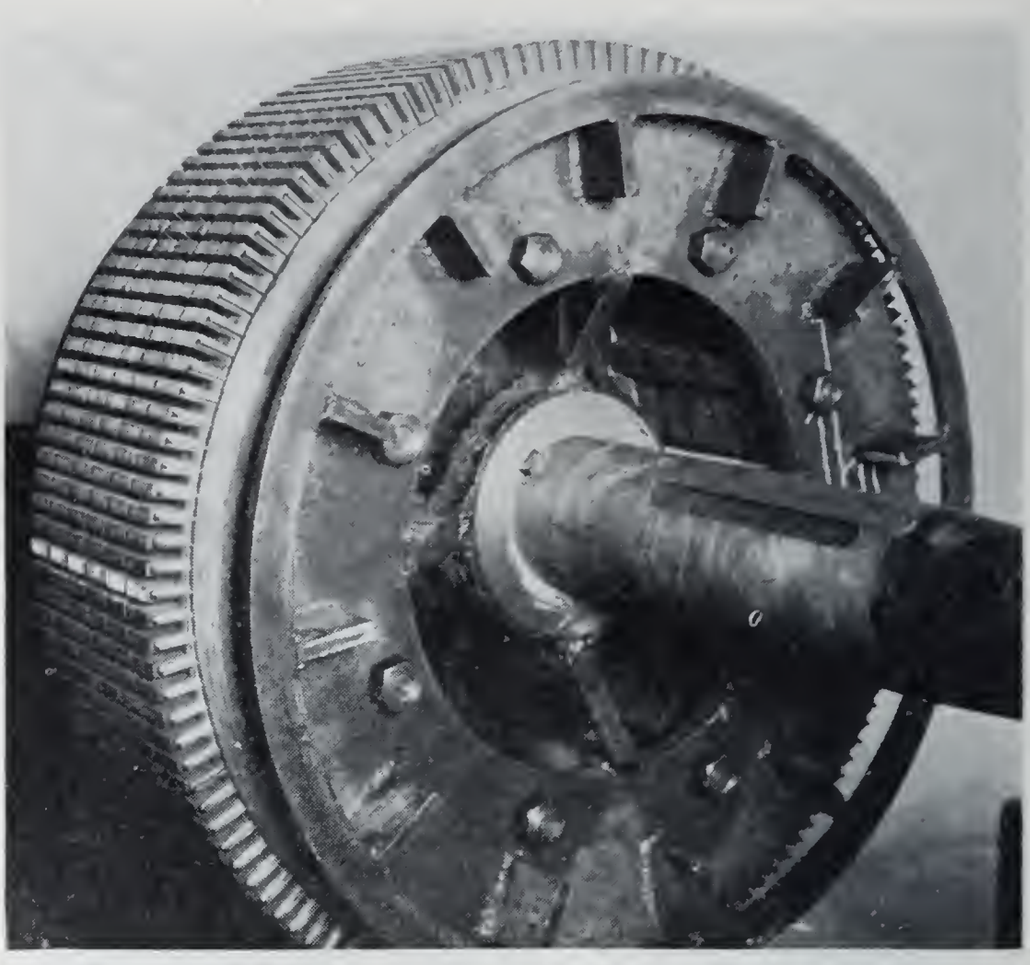

Fig. 6. Welded Construction.

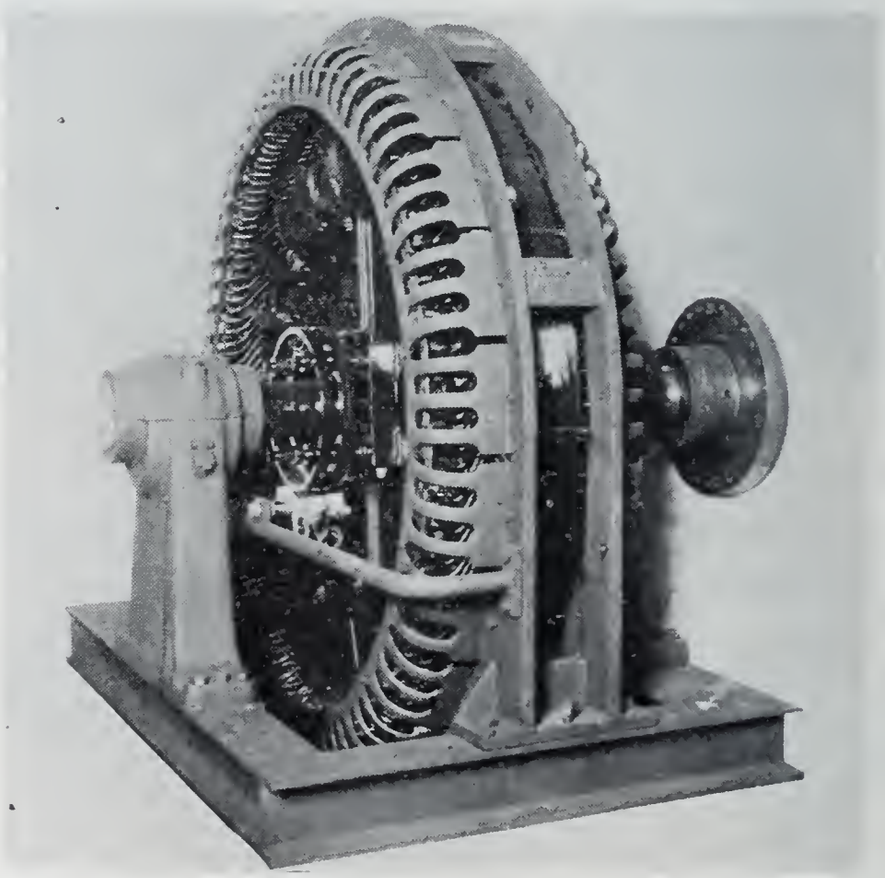

Fig. 7. Welded Synchronous Motor.

Fig. 8 shows a portion of the frame for a vertical water-wheel generator, entirely constructed by arc welding, having an overall outside diameter in excess of 33 feet.

Fig. 8. Welded Frame for Generator.

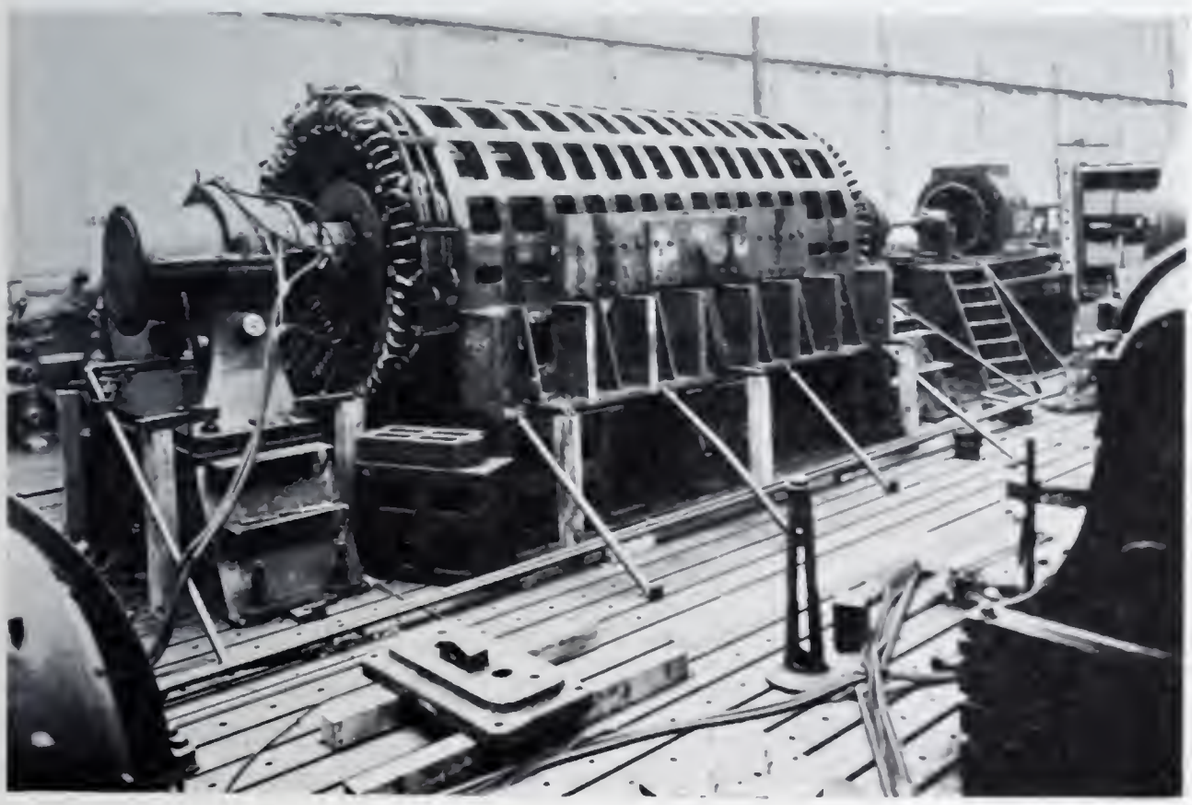

Fig. 9. Frame for Turbo-Generator.

Fig. 9 illustrates the arc-welded skeleton frame for the turbo-generator of the Hell Gate Bridge plant of the United Electric Light & Power Company. This is the largest turbine built so far for 3600 r.p.m. It is constructed in one piece, completely wound and shipped as a unit. This would not have been possible if a cast frame had been used. The weight of the frame, including the winding as shown, is 265,000 pounds.

Fig. 10 illustrates the various stages of construction of a turbo-generator, of 10,000 kilovolt-amperes, and 3600 r.p.m.

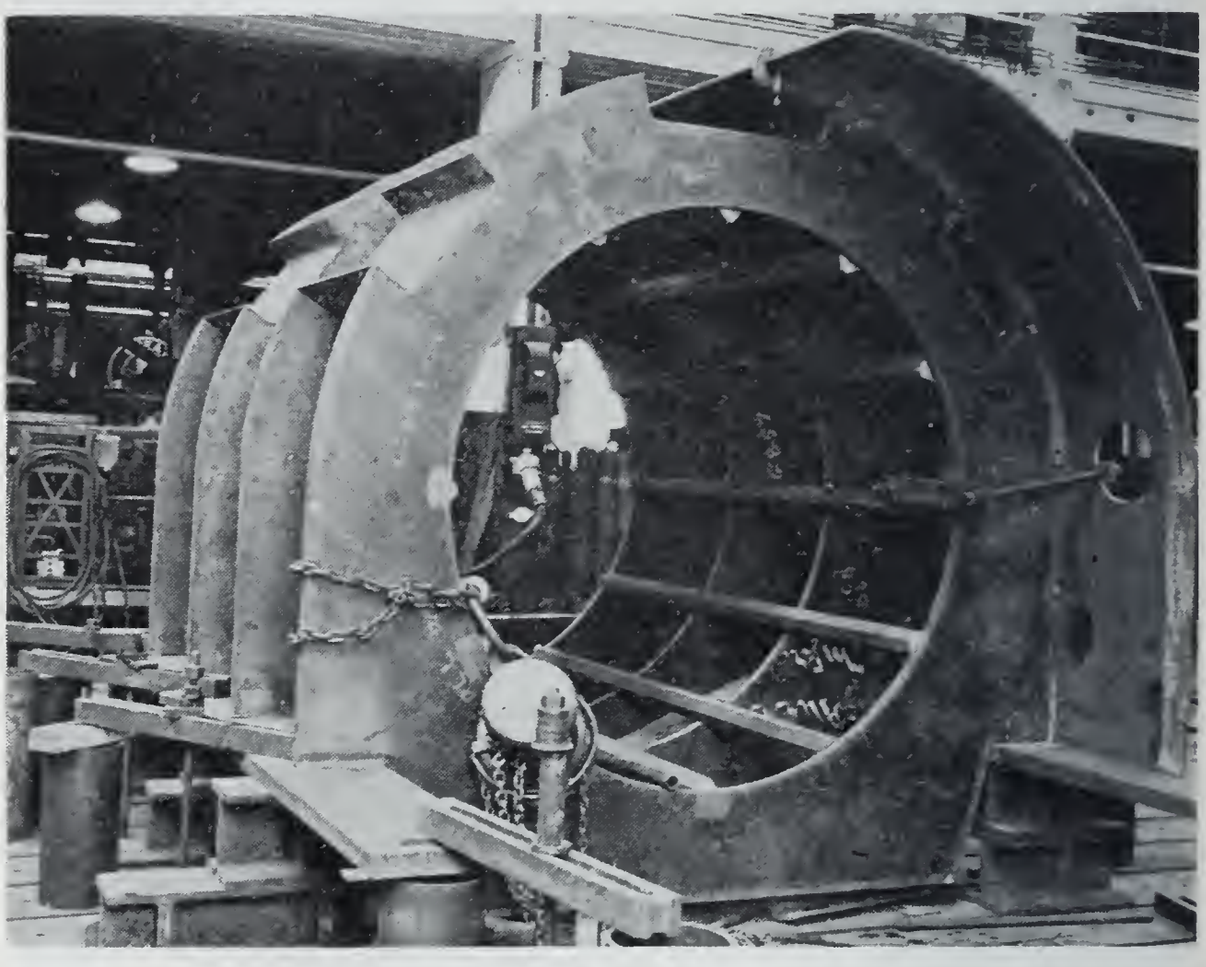

Fig. 10. Construction of Turbo-Generator.

H. S. Ayres:* In the making of slot welds, is the whole area of the slot welded and considered effective, or only a fillet around the edge; or if in place of a rectagular slot, you punch a hole, say 15/16 inch in diameter, is the whole area of that plug weld effective, or do you consider only the width of the fillet around the edge?

*Designing Engineer, Bureau of Bridges, City of Pittsburgh, Pittsburgh.

Another question is as to whether any treatment is required for old material that is rusted or painted, to make the material take the weld metal.

F. T. Llewellyn: I would recommend that in case of a slot weld the joint be figured for shear, which is practically equivalent to figuring only the fillets around the slot. Slot welds have not been used in many jobs. Where they were used they were satisfactory.

In the case of a punched hole, I am going to urge a little caution. If you punch a 15/16-inch hole, say in thick material, for plug welding, you may not get a very good job. If you bevel the edge of the hole you will have a better chance. I personally have not had the same experience and therefore not the same confidence, in the strength of a plug weld, particularly with a small hole, as I have in other forms, so I would go a little slow on the punched hole proposition.

G. L. Taylor:* Our Company has not had the opportunity of participating in the construction of any of the larger structures which have been talked about to-day, but the processes of welding have been used considerably in our shop practice. We have found various parts of different structures which can be handled with greater economy by welding. This is particularly true in the case of hoppers, which are required to be dust-proof. It is necessary to use quite a weight of material and a large number of rivets to make such hoppers satisfactorily, and frequently after that is done some welding is required to make them tight. They can be manufactured wholly by welding at a considerable saving in material and economy in the cost of shop work. We can also mention the fabrication of lintels by welding, as plates and angles to hold brickwork can be attached to the main sections efficiently and economically by welding.

I feel that the future of welding in the shop depends to a great extent on designing to effect saving in material, which point has been touched upon by some of the speakers. So far as we can ascertain, we believe the only hope of economy in cost is where this element of saving material enters. This last statement I limit to shop work.

There are two propositions. We can either have a structure manufactured in the shop by the present methods and welded in the field, or we can have the reverse where the work is welded in the

*Chief Engineer, McClintic-Marshall Co., Pittsburgh.

shop and erected in the field by the present methods. The first case is illustrated by the building of the Westinghouse Electric and Manufacturing Company at Derry, Pa. There no welding was done in the shop and only such fabrication as was necessary to put the work together in the field. After the steel was erected, all the work was welded in the field. This building owes its economy in cost to the fact that the welding was restricted to the field and the weight of material and cost of fabrication in the shop reduced to its lowest point.

I do not wish to take the attitude in any way of opposing the progress of welding. But I feel that some of the claims made for it are extravagant and that some of these claims are based on facts which have nothing to do with the process itself.

As an example, our attention has been drawn to the continuity of the purlins of the building at Derry. Our past experience has made this a factor which we are very loath to consider on account of the difficulty in actually securing it. Continuity can not be relied upon unless the foundations of the building have been constructed to exact location and are unyielding. I have frequently had occasion to look after mill buildings that have been up for some time and scarcely ever, after a period of years, has there not been considerable settlement, generally irregularly distributed. It is impossible to rely on any increased strength due to continuity of steel members under such conditions.

Professor McKibben made reference to saving of fillers under stiffeners where welded bar stiffeners are used, but such saving can be made in riveted construction and this is frequently done where stiffeners are crimped. A comparison has been shown in connection with the building of the General Electric Company, in Philadelphia, between a welded truss made with rolled H-column chord sections and a riveted truss where the top chord is constructed of two angles and a channel. It is just as possible to make riveted trusses with rolled H-sections as to make welded trusses, and there is no reason for claiming economy of design of this character as due to the processes of welding.

In other words, we are anxious to consider all true economies effected by welding processes, but do not wish to be led astray by matters which do not arise from the process employed.

RICHARD KHUEN, JR.:* Welding on buildings is a simple operation. The principal difficulty is in erecting the building and keeping it in line on account of insufficient connections. You must have sufficient bolted connections to hold the building in line after you get it in proper alinement, until the welding is done. We have no trouble in making good welds, but the other is a constant trouble, because you are trying to reduce the number of holes in the structure for field connection. It is well known that a great many of the bolted connections are entirely satisfactory in unimportant members. I would say to design the structure so that wherever you have important joints you can make the bolts less in number and weld these particular connections, leaving everything else that is of no importance bolted. You must not forget, then, that when you weld a structure in the field you have to hold the members and the structure in position and you want to be sure to have enough bolted connections so you can do it. The welding can be done very simply after that.

*Manager of Erection, American Bridge Co., Pittsburgh.

OXY-ACETYLENE WELDING OF STEEL*

By S. W. Miller†

INTRODUCTION

The oxy-acetylene flame is formed by the combustion of acetylene in the presence of commercially pure oxygen. It produces a temperature (as determined by some German tests) of about 3100 degrees C. or 5600 degrees F., which checks quite closely with the temperature theoretically determined by Prof. Joseph W. Richards,‡ of 3000 degrees C. or 5400 degrees F. Of course such a temperature is sufficient to melt any metal, and, as the heat is concentrated in a small space, it is easy to melt the edges of pieces to be joined, and allow the melted metal from them to run together, thus forming a solid joint.

In thin material, up to say 1/8 inch in thickness, it is not necessary to prepare the edges of the pieces to be joined in any way, except to see that they are clean and that they fit well together. With thicker material, if the weld is expected to penetrate entirely through the joint, it is necessary to bevel the sheets so that the weld metal can be built up from the bottom of the V so formed, and, where it is used, it is obviously necessary to add metal to fill up the groove. In the early days, the welding rod employed for this purpose was practically always Swedish wrought-iron. It was low in carbon and therefore low in tensile strength, but had considerable ductility in the weld as measured in the ordinary tensile test. Beginning about 1914, this material could not be obtained in this country and, as a substitute for it, low-carbon steel wire carefully made by the open-hearth process was substituted, and gave about the same physical properties in the weld. Its ultimate strength was as a maximum from 50,000 to 52,000 pounds per square inch, while that of steel plate ordinarily used would range higher, say from 55,000 pounds up. This meant that tensile test-pieces would almost always break in the weld, when it was of the same section as the plate.

About 1916, the idea began to develop in this country that it would be advisable to make the weld always of greater strength than

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†Consulting Engineer, Union Carbide and Carbon Research Laboratories, Inc., Long Island City, N. Y.

‡Private communication, Oct. 15, 1916.

the plate, even when it was of the same section, and since that time a number of welding rods have been developed that will give ultimate strengths of from 65,000 to 70,000 pounds per square inch of weld metal. Much higher results have been obtained in laboratory tests, strengths of over 100,000 pounds being not uncommon.

Most of the steel material that is now welded is plate or sheet of about the following physical characteristics:

Ultimate strength = 45,000 to 65,000 pounds per square inch.

Yield-point (minimum) = half the ultimate strength.

Percentage elongation in eight inches (minimum) = 1,500,000 divided by the ultimate strength.

Percentage reduction of area = 50 to 60, although the reduction of area is very seldom specified.

The chemical composition is within the following limits:

	Per cent.
Carbon	0.15 to 0.30
Manganese	0.25 to 0.50
Sulphur	0.05 maximum
Phosphorus	0.05 maximum

Steel having these physical and chemical properties may be furnished in different grades from fire-box, through flange and ship-plate to tank steel, fire-box steel having the best quality. There is no way to evaluate the quality as it is governed by the raw materials used and their treatment in the furnace, and, as the above physical and chemical properties may be obtained in any one of the four grades of steel mentioned, these properties will not of themselves insure good quality, so that for important work it is wise to use steel known to be of high quality, such as fire-box or flange steel.

For structural steel there are quite a number of specifications which differ slightly from each other as far as physical and chemical properties are concerned, but are still subject to that indefiniteness of quality referred to above. Quality does have some effect on the results of welded structures, especially in the case of boilers and pressure vessels. In structural steel, the type and design of joint can usually be selected, so that any ordinary irregularity in the steel may be left out of consideration.

Steel castings can usually be welded satisfactorily, but, as there

are at times variations in their welding quality, and as they have not received any work such as forging, they should be tested for welding quality where strength and reliability are important considerations.

In plain carbon steels, the carbon should not exceed 0.30 per cent. if good results are expected, and it is better to stay below 0.25 per cent.

The welding of alloy steels which depend for their high strength on heat treatment should be considered carefully with regard to design, welding material, and ability of the welder. On account of the metallurgical conditions involved, special knowledge and skill are required if the best results are to be obtained, so that each case must be considered on its own merits.

In the last year or two, steels containing large percentages of chromium have been developed for services which require resistance to heat or corrosion. Most of these can be welded satisfactorily if proper precautions are taken. The methods and procedure to be followed with these alloys are well described in a paper by W. B. Miller.[1]*

In order that satisfactory results may be had with welding, proper procedure must be followed, just as is done in any other work. It is always true that good design, proper materials, correct methods, and adequate inspection and testing should be used in any construction, and it has become second nature for us to use them in other work than welding without thinking very much about them.

DESIGN

Designing for welding requires the designer to know about the physical properties of welds and how they can best be employed. A design that is suitable for riveting, for example, is seldom suitable for welding, and it is advisable to use butt-joints instead of lap-joints if the maximum economy in material is to be obtained. For maximum strength, welds should be made from both sides of a butt-joint, because when made from only one side there is a tendency for the penetration to be incomplete, leaving a notch at the bottom of the weld, which of course weakens it. Welds at the corners of two plates at right angles to each other should be avoided if the stress is high, the same difficulty existing as with single-vee welds.

*See references at end of paper.

The physical properties of oxy-acetylene weld metal are about as follows (as found from welds in steel plate):

Low-carbon steel welding wire

Ultimate strength (maximum).....52,000 pounds per square inch
Yield-point (maximum).....42,000 pounds per square inch
Elongation by the bend test[2, 3].....25 per cent.

In compression, the value is about the same as in ordinary soft steel, about 90,000 pounds per square inch. In shear, the ultimate strength is about 35,000 pounds per square inch.

Where welding wires giving higher strength are used, the following physical properties may be obtained:

Ultimate strength.....65,000 pounds per square inch
Yield-point.....45,000 pounds per square inch
Elongation by the bend test.....25 per cent.
In compression (ultimate).....90,000 pounds per square inch
In shear.....40,000 pounds per square inch

The above figures for tension have been obtained from double-vee welds carefully made, and somewhat smaller amounts should be used in design, as it is not reasonable to expect that the best workmanship can always be obtained.

However, it has been found perfectly possible with only an ordinary amount of training of the welder, to obtain the following results, which are perfectly safe to use in design, provided it is known that the operators are competent:

Ultimate strength in tension
pounds per square inch

Low-carbon steel wire.....45,000
Special wire.....52,000

Ultimate strength in shear
pounds per square inch

Low-carbon steel wire.....32,000
Special wire.....38,000

The tensile figures are for double-vee welds. Single-vee welds made with low-carbon steel wire are not nearly as reliable as those

made with the special wires, the latter making it much easier for the welder to secure thorough penetration. In fact, with such wires and careful work the full strength of the weld metal may be developed, which is exceptional with low-carbon steel wire. However, it is better to keep the fiber stress low in single-vee welds even with tested welders.

All the figures for tensile strength given above have been obtained from specimens in which the weld has been machined or ground flush with the plate, so that they are both of the same section. In practice, welds are always reinforced more or less to take care of slight irregularities. The amount of reinforcement may well vary with the strength of the weld metal, being less as the strength increases. For low-carbon steel wire, it has been customary in important cases with double-vee welds to specify a reinforcement on each side of 25 per cent. of the plate thickness. With welds of higher strength, this is evidently unnecessary and 15 per cent. would seem to be ample. For single-vee welds, it is not advisable to reinforce very much, say not over 20 per cent. of the plate thickness, because a heavy reinforcement means an eccentric load, and this may mean weakening the joint rather than strengthening it, because of the increased stress at the bottom of the vee. In addition, there is the concentration of stresses at the junction of the heavy reinforcement and the plate, which has been found by actual test to be much greater than would be apparent. The former condition also exists, although not to the same extent, in a single-vee weld that has had the bottom of the vee gone over to remove any defects; while in the true double-vee weld its effect is very slight.

Welds in shear are practically always of the fillet type, and the section along which they fail is the plane perpendicular to the top face of the weld. In such welds it is well to make allowance for some imperfections at the bottom of the vee because it requires careful workmanship to get complete fusion to the root of the angle, and it is suggested that the section be taken as the actual distance less 1/16 inch.

MAXIMUM ALLOWABLE FIBER STRESS

It is customary in designing a structure to use some ultimate strength of the material, divided by a factor of safety of varying

amount, say from 4 to 6 or more, depending on the service conditions. This factor of safety is determined by experience and engineering judgment. If we knew exactly the maximum stress to which any structure would be subjected, we could with perfect safety use a working fiber stress of somewhat below the yield-point. The difficulty is that we do not know what stress may come on the structure, and our judgment urges us to make it safe by not using too high a working stress. I think that all engineers agree that a certain amount of ductility is necessary in the steel of which the structure is made—just how much of course is hard to say—so that even under abnormal stresses, while it may distort, there will be little tendency for it to rupture suddenly.

While the amount of ductility necessary is not definitely known, it would seem clear that the allowable fiber stress would depend directly on the ultimate strength, and, from our experience with structures that have given good service, we may be able to produce an empirical formula that will give due weight to both ductility and tensile strength. Formulæ of this type have been proposed by Mr. A. B. Kinzel.[4] At the request of the author, Mr. Kinzel also prepared a formula to cover the conditions existing in welds in pressure vessels, a paper on the subject having been written by the present author.[5]

A welded piece is not homogeneous, the weld having different physical properties from those of the base metal. One of the more important differences is that the yield-point of the weld metal is higher than that of mild steel, so that an ordinary tensile test does not show the true elongation of the weld metal, to determine which it is necessary to resort to elongation as determined by the bend test. It is, of course, possible, where the weld is large enough, to cut tensile test-pieces from it and use their physical properties in the preparation of a formula, but this is in most cases difficult, and in any case slow and expensive. It is much more practical to use the bend test, and it has been found by experience that the results of this test properly made are accurate and consistent.

The formula is, $S = \frac{T}{7.15} \sqrt[3]{\frac{E}{10}}$, in which S = maximum allowable working fiber stress, pounds per square inch; T = ultimate

tensile strength, pounds per square inch; E = elongation, in per cent., shown by test specimen subjected to free and unrestricted bending.

TABLE I. PROPOSED MAXIMUM ALLOWABLE WORKING FIBER STRESSES IN POUNDS PER SQUARE INCH OF PLATE SECTION FOR WELDED STEEL PRESSURE VESSELS

Per cent. elongation by bend test	Ultimate strength in thousands of pounds per square inch							Factor of safety
	45	50	55	60	65	70	75	
5	5000	5600	6100	6700	7200	7800	8300	9.
7½	5800	6400	7000	7700	8300	8900	9600	7.8
10	6300	7000	7700	8400	9100	9800	10500	7.15
12½	6800	7600	8300	9000	9800	10500	11300	6.65
15	7200	8000	8800	9600	10400	11100	12000	6.25
17½	7600	8400	9300	10100	11000	11700	12700	5.9
20	8000	8800	9700	10600	11400	12300	13200	5.7
22½	8300	9200	10100	11000	11800	12800	13700	5.5
25	8600	9500	10500	11400	12400	13200	14200	5.3

Table I gives the results for a number of different conditions. It will be seen from both the formula and the table that the effect of the tensile strength varies directly as its amount, while the elongation effect varies as the cube root of its amount, meaning that an increase in ductility does not give a corresponding increase in working fiber stress. This seems to be in accord with good engineering practice and judgment, in that there is no apparent reason why ductility beyond a certain amount is of any particular value.

In the application of the formula, it is evident that the tensile strength and elongation figures used in any calculations must be the lesser of those of the base and weld metals. The elongation of good steel plate by the bend test is of the order of 80 per cent., but no ordinary structure is built of a solid piece of such material. Drilled holes in such plate result in reducing the elongation to say 25 per cent., with which is fairly comparable the average elongation of good weld metal of say 20 per cent.

It should be remembered that the above formula was devised for use in welded pressure vessels, and that it may not be applicable to other welded structures, for which changes in the constants may be required. Also, the use of any such formula should be restricted to the conditions for which it was devised. A weld may be perfectly safe in a structure containing columns, but no engineer would omit

to consider the strength of the column as such. Again, in lap-joints the maximum stress often depends on the eccentric loading due to the lap, and this must be considered apart from the strength of the weld.

EFFECT OF HEAT ON BASE METAL

Much has been said, and I am afraid with little real basis of thought, about the adverse effect of the welding heat on the base metal, but anyone who has seen good welds tested by sledging them when clamped on an anvil or held in a vise, will certainly not feel that there has been any serious injury to the metal. In one published instance, actual test-pieces were taken from the base metal as close as possible to the weld.[6] There were nine of these pieces. The mill-test report of the plate showed as follows:

Ultimate strength .....57,440 pounds per square inch
Yield-point .....36,500 pounds per square inch
Percentage elongation in eight inches.....30.25

The average test results from the nine pieces were:

Ultimate strength .....59,600 pounds per square inch
Yield-point .....35,900 pounds per square inch
Percentage elongation in two inches.....34.6
Percentage reduction of area..... 58

The average test results from 10 pieces cut from different parts of the head away from the welds, were:

Ultimate strength .....59,000 pounds per square inch
Yield-point .....40,100 pounds per square inch
Percentage elongation in two inches.....32.8
Percentage reduction of area..... 63

It appears clear from these figures that there is no material difference between the plate itself and the material next to the weld.

We should also remember that we are not stressing our steel structures above the yield-point in ordinary service, as they are designed with a considerable factor of safety; further, that the modulus of elasticity of good weld metal is equal to that of ordinary steel, so that below the yield-point, where the structures are stressed, there is the same elongation in both the weld and the base metals.

Welding is no exception to the rule that any structure must be properly inspected and tested before it is put into service, and that

proper workmanship and supervision must be furnished during its construction. That these important matters can be successfully taken care of has been proved in hundreds of cases, and definite instructions can be provided for any work so that safe and satisfactory results may be assured.

As in any other work, the operator must be properly trained. The best way to do this is to start with comparatively thin metal, cutting test-pieces from the welded plate (Fig. 1 and 2) and bending

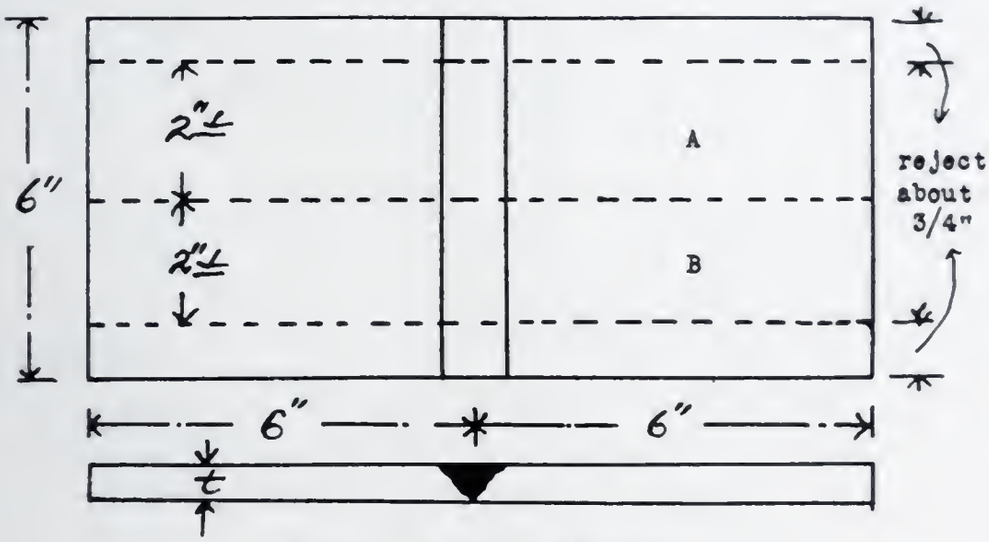

Fig. 1. Test for Welders.

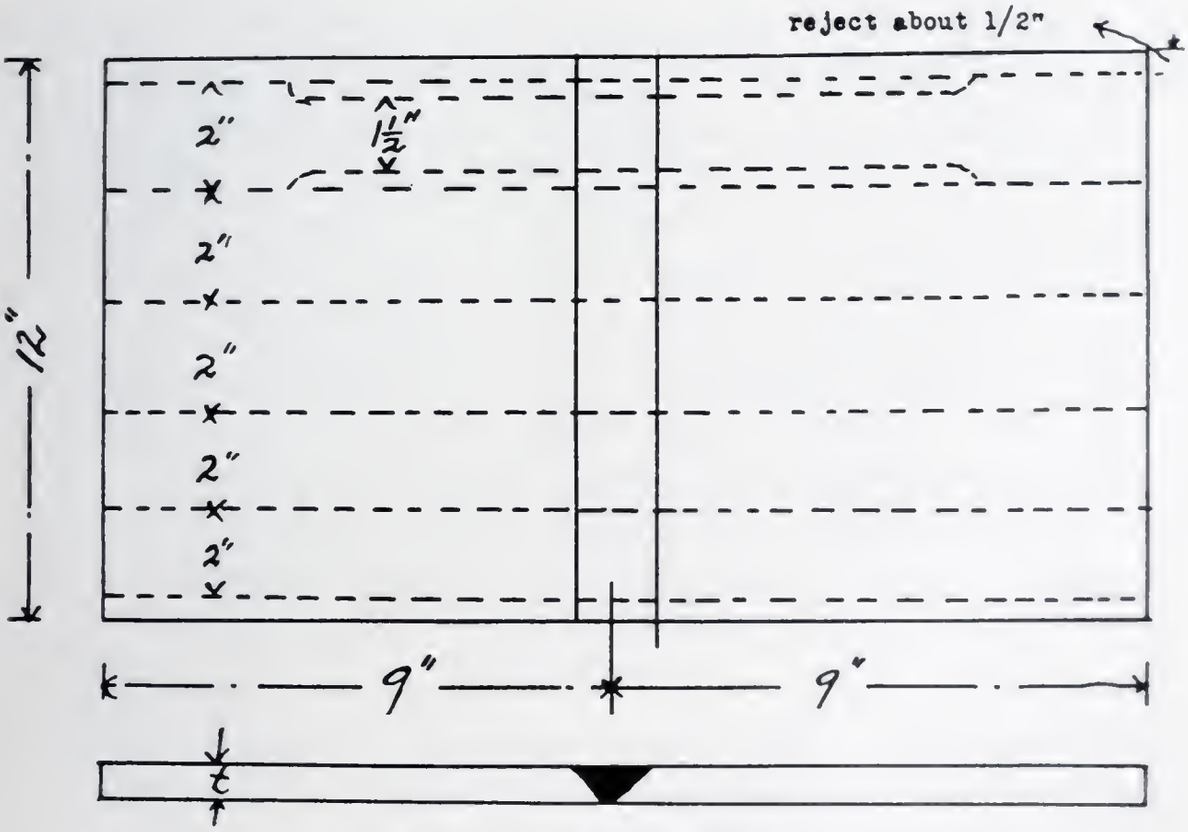

Fig 2. Test for Welders.

some of them forward and some backward in a vise with a hammer. This will show up any defects, such as lack of fusion or penetration, and the instructor can point these out and advise the means for correcting them. The thickness of the plate should be gradually increased until that to be actually used is reached. With heavier plates, it may be necessary to clamp the test-pieces on a side of the anvil with a heavy C-clamp, as a vise may not be strong enough. Single-vee welds should be used in this test until the welder has shown his ability to get full penetration, and the reinforcement should be machined or ground off. This test may seem crude, but it is exceedingly effective and rapid, and shows up the defects just as well as does the tensile test, although of course it is not quantitative.

In Fig. 1 and 2, t is the thickness to be tested. The included angle of vee is 90 to 100 degrees. Use any welding plate that welds well; the welding rod should be that to be used on the regular work. Grind or machine off reinforcement and bottom of vee with grinding or tool marks lengthwise of the piece, and leave surfaces reasonably smooth. In Fig. 1, bend A forward and B backward. In Fig. 2, cut five pieces out of the plate after welding, using a cutting torch and following the outline of the test-piece. If greater accuracy is desired, mill the edges of test-pieces.

When the welder has arrived at the point where he can show good results under the bend test, it is wise to find out what he can do quantitatively, and for this purpose, test-pieces should be prepared somewhat more carefully, although for all ordinary purposes it is not necessary to machine them. They can be cut with a cutting torch if a smooth cut can be obtained, and any slight irregularities may be removed by grinding. Of course a mechanically driven cutting torch is better for this purpose than one operated by hand, because the cut is smoother. It has been found advisable to use test-pieces made in accordance with Fig. 2 to get a fair average of the welder's ability.

With low-carbon steel wire, the following results should be obtained—average of the five test-pieces, 45,000 pounds, with a minimum of any one piece of 42,000 pounds. When stronger welding wire is used, the average should be 52,000 pounds, with a minimum of 50,000 pounds. These figures can easily be reached by competent welders, and are not the maximum obtainable. They may be used safely in specifications, which may well require that no operators be

employed unless they can meet these requirements. The specification may also require that the engineer has the right to call for a reasonable number of test plates during the progress of the work.

Adequate supervision must be provided during the work as in all other cases. The supervisor should be a competent welder, able to test the men, correct their defects, and see that they follow the procedure laid down. Such supervision was provided in the case of a pipe-line 140 miles long, the welders having been instructed and tested before the work was started. Each supervisor had charge of about ten welders. There were about 18,000 welds in this line, and the only defects that were found were four pinholes that needed only calking, which shows the possibilities of proper training and supervision.

The engineer's inspector should be a qualified welder, of course having the other characteristics of a good inspector. Being a welder, by simply watching the operator he will be able to tell at any time whether good work is being done, and will be able to insist on proper work. The method of testing a welded structure will of course vary with the structure. In the case of pressure vessels, it is customary for our own work to require that a hydrostatic test of twice the working pressure be applied, and that all welds be struck with a sledge of appropriate weight while under this pressure. The pressure is then raised to three times the working pressure and held there for three minutes, the fiber stress at this pressure being 27,000 pounds per square inch. As the tanks must be perfectly tight, they are afterwards subjected to air pressure at 1½ times the working pressure, and the welds tested with soapsuds. In over seventy tanks, designed for working pressures up to 300 pounds, having thicknesses up to 1¼ inches, these tests showed the tanks to be free from even a pinhole leak.

All of the above items may be embodied in what may be well called a procedure control. Of course, the details will vary with the work, but many such procedure controls have been written, and following them has resulted in work that has given entire satisfaction.

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DISCUSSION

C. S. Davis, *Chairman*:* I am sure you have all enjoyed this most excellent paper and later on you will have an opportunity to discuss it. But before entering upon the discussion we want to pass on to another form of welding, which is older than either of the two we have been considering and that is forge welding. We have some moving pictures which will be presented by Mr. Texter of the National Tube Company.

C. R. Texter:† I haven't a paper to read and, fortunately for you, I will not talk very long. We are fortunate in having a reel of motion pictures which shows the hammer welding, or as you call it the forge welding, of steel pipe. We know that by looking at this picture you will obtain a far better idea of what the National Tube Company is doing in the way of making pipe by this method, than you could possibly derive by any verbal description I could give you. If you think the picture starts rather abruptly please remember that this is the fifth reel of a series which the National Tube Company has, describing the manufacture of the various kinds of steel pipe such as lap weld, butt weld, and also hammer weld. The five reels

*Consulting Engineer, Pittsburgh.
†National Tube Co., Pittsburgh.

would take you through all the various processes involved from the ore to the finished product, and would consume entirely too much time. We have therefore selected this one reel as being most appropriate for the occasion. Furthermore, if it ends rather abruptly please remember that we have eliminated some extraneous material at the end.

In this picture we will start with the steel plates, showing how they are bent into the form of pipe, heated by water-gas, a section at a time, and then hammer welded or forge welded. After the entire length has been welded it is thoroughly annealed and passed through various finishing operations.

At the conclusion of the showing if there are any questions I can not promise to answer all of them, but I am fortunate in having with me Mr. Paine, assistant superintendent of our hammer-welding plant, who will answer any questions you may wish to ask.

C. S. Davis, *Chairman*: I am sure we have enjoyed this film and I am confident that there will be some questions to answer in connection with it. Before entering into the discussion, we have some slides showing actual work done in Europe. These slides will be presented by Mr. F. J. Giroux.

F. J. Giroux:* During a recent trip through Europe in the interest of electric welding, I visited manufacturing companies in Switzerland, Germany, France, England and Belgium.

Secret processes of manufacturing are used in most parts of Europe, and this also applies to the methods of electric welding. Many large companies do extensive welding.

The cost of labor is very low; for example, a welder in Belgium gets 15 cents an hour. This is the reason automatic welding is not used.

John J. Crowe:† In the making of welded joints the problem is seldom one of welding, as most of the ferrous and non-ferrous metals and alloys can be welded without difficulty, but the stresses set up due to heating and cooling in the welded metal and the metal

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†Air Reduction Sales Co., Jersey City, N. J.

adjacent to the weld may cause failure unless the metal has the necessary elastic limit to resist these stresses, or sufficient ductility to permit yielding without failure. It is the control of these internal stresses that has made possible the welding of large and intricate members. The detrimental effects of these stresses may not only be overcome in many instances by proper design and proper welding procedure but may in some instances be actually used to make better welded joints.

The key-note of Mr. Miller's paper is engineering supervision. Until it is more generally realized that the future of welding is dependent on proper engineering control and supervision, welding will not receive the standing to which it is entitled. Practically every failure of a welded joint is attributed to faulty welding, if the failure be through the weld; whereas, in many instances, the failure is due to improper design. Using engineering methods, Mr. Miller has developed a formula for evaluating welded joints which takes cognizance of two important variables—elongation and tensile strength. While we may not agree with this formula as to details, it must be admitted that in principle it is a step in the right direction and is certainly better than anything we have at the present time.

Two points in connection with this formula should receive careful consideration:

1. Do the variables selected—that is elongation and tensile strength—afford the best criterion for evaluating welds?

2. What are the limitations of the formula?

With reference to the first it would appear that the elastic limit might properly be substituted for the tensile strength of the constants in the formula were changed accordingly.

Referring to the author's values for the tensile strengths of welds made with low-carbon welding rods, and for the special rods, it will be noted that the joint efficiency of the welds made with the special rod is 25 per cent. greater than the joints made with the low-carbon rod, when tensile strength is used as a standard of comparison, but only seven per cent. greater when compared on the basis of yield-points.

Professor Moser* recently reported the results of tests made at elevated temperatures. For oxy-acetylene welding two types of filler material were used—one a typical low-carbon filler rod, and the other a self-fluxing rod evolved for the purpose of developing greater ultimate strengths in the welded joint than was practicable with the low-carbon rod. The results of the tests of these joints given in the following table are exceedingly interesting.

Rod	Temperature degrees F.	Pounds per square inch: Proportional limit	Pounds per square inch: Ultimate
13	78	36,000	57,200
13	78	36,000	53,600
Average	78	36,000	55,400
1	78	25,000	68,700
1	78	25,000	68,650
Average	78	25,000	68,675

It will be noted that welds made with rod No. 1 had an ultimate strength 24 per cent. greater than the welds made with rod No. 13; but, if the comparison be made on the basis of the proportional limits, it will be noted that rod No. 13 (low carbon) has a joint efficiency 44 per cent. greater than the joints made with the special rod.

As the temperature is increased, the ultimate strength of the joints made with both rods increased, the low-carbon weld reaching a maximum of 73,000 pounds per square inch at 450 degrees F. and the welds made with the special rods a maximum of 76,000 pounds per square inch at 500 degrees F.—a difference of only four per cent. The proportional limits in both cases showed a rapid decrease in temperature and at 575 degrees F. was 16,000 pounds per square inch for joints made with either type of welding rod.

With reference to the second point, and also showing the danger of drawing erroneous conclusions from the tensile strength of a

*Elevated temperature tests of welds, by Charles Moser and K. V. Laird. Journal of the American Welding Society, 1928, v. 7, p. 128-143.

welded joint, R. R. Moore* in his investigation made at McCook Field showed that it was possible to develop a greater tensile strength with an alloy filler rod than was possible with a low-carbon rod and that, with the usual type of reinforced weld, the failures invariably occurred in the tubing and not in the weld when the specimens were tested in tension. These same types of joints, however, when tested for fatigue, showed the welds made with low-carbon filler rods to have an endurance limit 100 per cent. greater than the joints welded with the alloy rods which gave the higher tensile strengths.

If, as the paper states, the yield-point of the weld metal is higher than that of the parent metal, should not this fact have some consideration in the development of future formulæ.

Another point on which more information will be required if consistent results are to be obtained is the method of measuring the elongation in the bend test. If the gage marks are close together, the elongation as measured with a flexible scale or a dioptometer may be the same; whereas, if the distance between gage points be increased, the percentage of elongation as measured with a flexible scale will be less, while the percentage of elongation as measured with the dioptometer may be greater and in extreme cases may be infinity.

In Switzerland, Sulzer Brothers, manufacturers of large welded boilers and pressure vessels, are applying many of the principles of procedure in control and testing which have been described in this paper, but the bend values are expressed in Tetmajer units which vary directly with the thickness of the specimens and inversely as the radius of the curvature of the bend. The welders are examined frequently and are required to make test welds whenever there is a change in work, apparatus, or other conditions.

S. W. Miller: I would like to make it very clear that I did not say that the formula as it at present stands can not be modified or should not be modified. Nobody ever yet introduced anything novel into the engineering field that was not subject to criticism and that should not be subject to criticism, provided the criticism is constructive. I think it would be interesting to have a number of formulæ devised based on these different physical properties. Mr.

*Fatigue of welds, by R. R. Moore. Journal of the American Welding Society, 1927, v. 6, p. 11-32.

Kinzel's paper read before the St. Paul meeting of the American Society of Mechanical Engineers last August goes into the matter in much more detail entirely aside from welding. He has suggested computations depending on conditions. For instance, the ultimate strength in deep drawing steel is of very little importance, and so the tensile strength for deep drawing steel should weight the formula very little. Its ductility should weight it very heavily. In ordinary engineering structures tensile strength is far more important than ductility, provided the ductility is sufficient.

As far as using the yield-point instead of ultimate strength is concerned, it is perfectly feasible to apply the formula. Evidently in the case of the ultimate strength where it differs between the weld metal and the base metal, the lesser of the two must be selected. There would be some question as to just exactly what to do in that case.

As far as ductility is concerned, I can say only that we based the formula on tanks that had given good service. I do not say that we should not use more fiber stress. I believe the time is coming when all boilers will be welded. And there is no reason why you should not use 100 per cent. strength of joint, and, if you can determine the working conditions closely enough, there is no reason why you should not go up to 15,000 or 16,000 pounds working stress, if proper procedure is followed. If you are not used to it, learn its possibilities. Plenty of people are able and willing to show you what can be done. Use your fine engineering judgment and design the things for welding, because, in my judgment, it is the coming method of joining metals.

Samuel E. Duff:* Early in the year 1921, in connection with the design of a special welded steel structural unit, I made a study of the theoretical economy possible by the use of plates rolled to a taper lengthwise. The rolling of steel plates with the thickness tapered in the direction of rolling can be effected in the last passes of a finishing plate mill.

My investigation showed the possibility of decreasing the total weight of steel required in construction units of many types, as much as 30 per cent. by the use of taper plates. This saving in weight is

*Consulting Engineer, Pittsburgh.

represented by the variation of the cross-sectional area of the taper plate in accordance with the stress requirements, instead of being limited to the use of a plate of uniform thickness, the area of which, while properly proportioned for the point of maximum stress, is excessive for the stress existing at other points.

Consideration of the requirements of various types of steel construction led to the conclusion that the use of about twelve standard rates of taper would suffice for commercial requirements. These are indicated in Fig. 3. The matter is covered by United States patents 1,574,563 and 1,652,860.

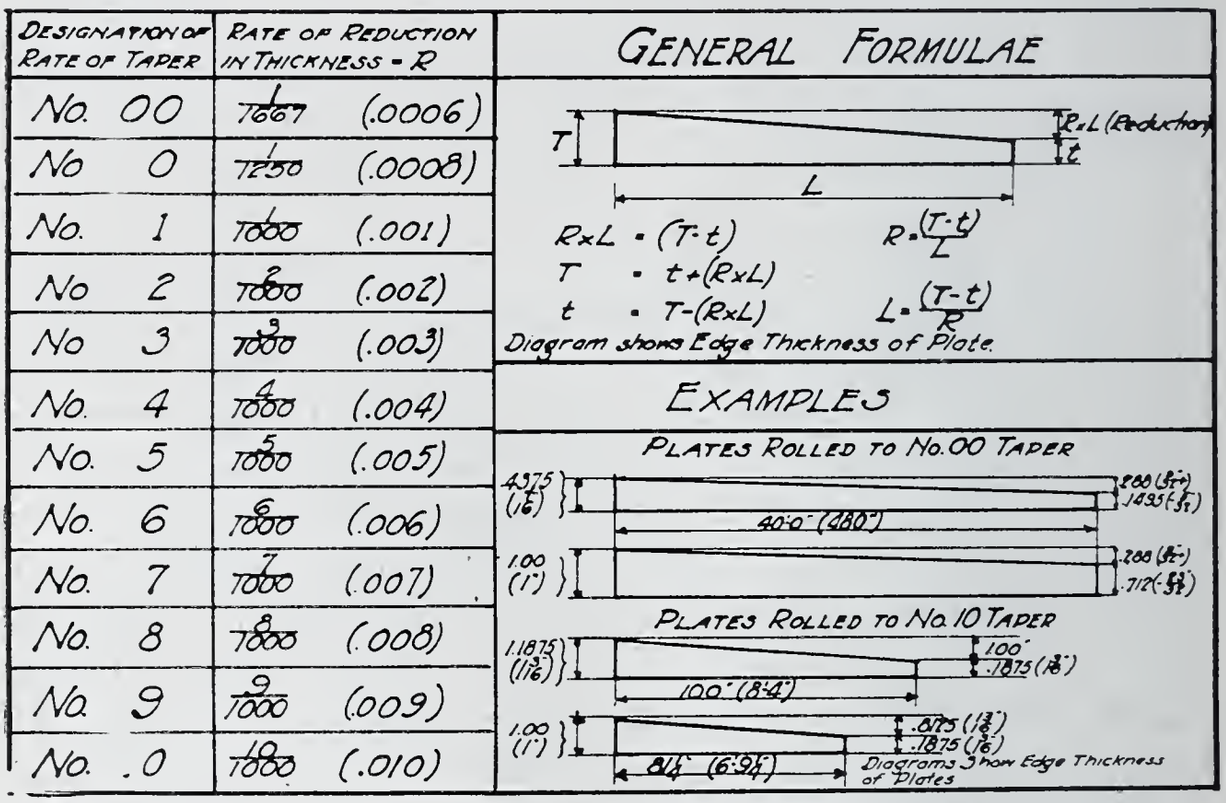

Fig. 3. Suggested Rates of Taper for Steel Plates.

As an example of a steel structure composed of tapered plates fabricated by welding see Fig. 4.

Considering the shell only of this standard 35,000-barrel steel oil-storage tank, the saving in weight over the usual riveted design is about 25 per cent. The saving in number of pieces to be handled (at least 25 per cent.) is also important, because it indicates reduction in erection costs, already greatly lowered by the absence of seam calking, which is not required with welded joints.

Fig. 5 is a comparison of rolled, riveted, and electric welded steel girder designs, showing a saving of about 20 per cent. in weight by the use of taper plates.

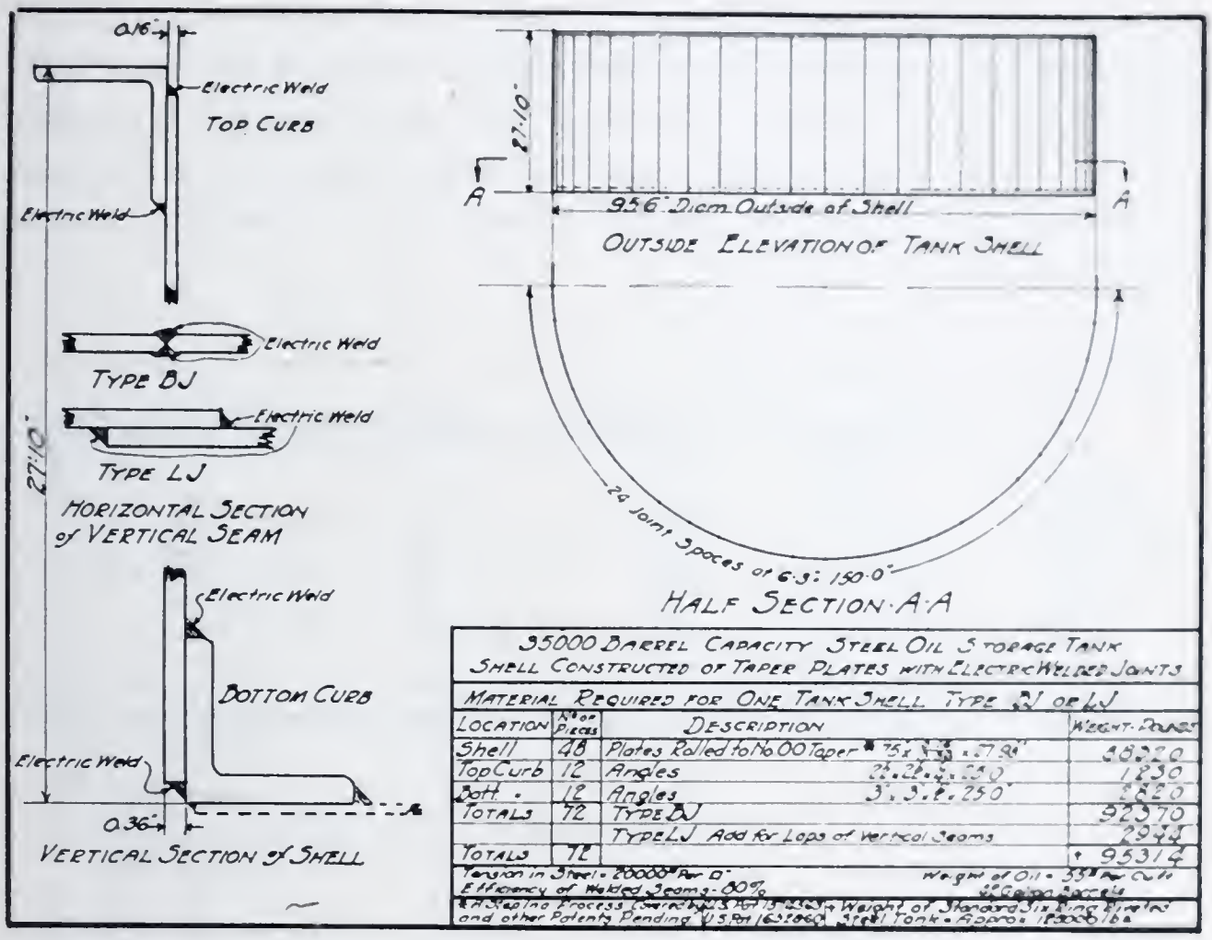

Fig. 4. Welded Construction Using Tapered Plates.

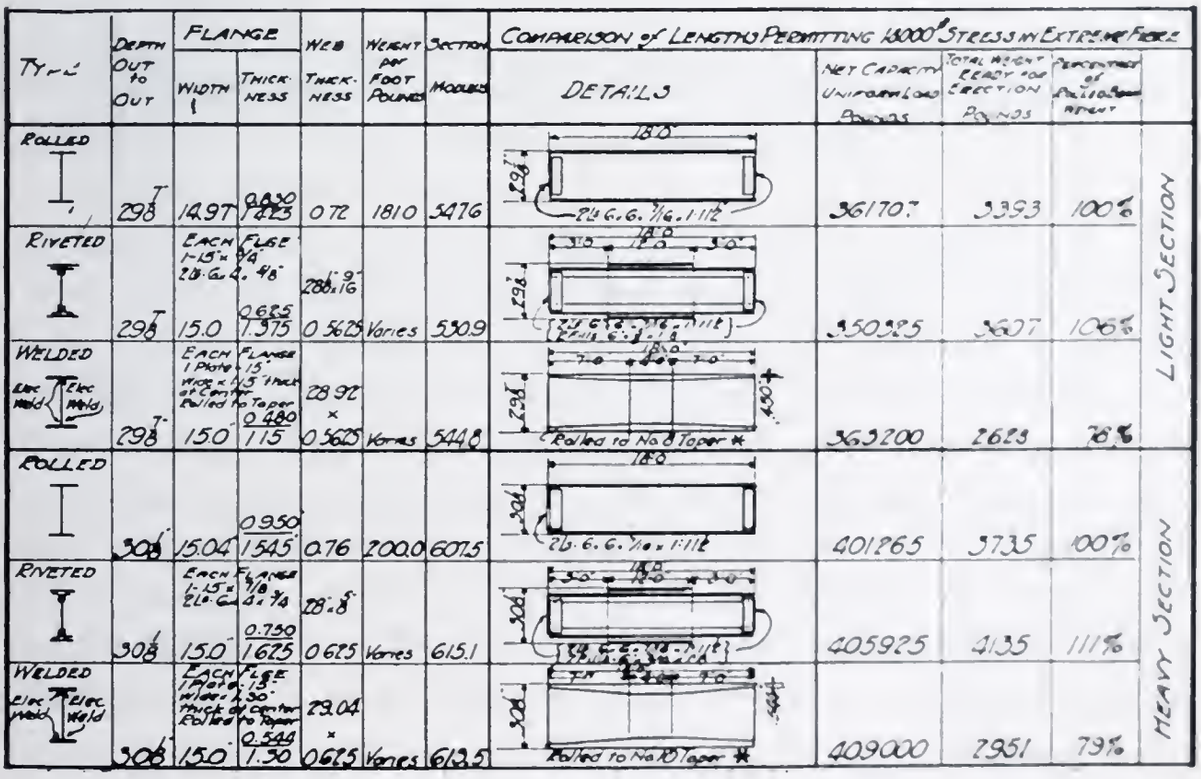

Fig. 5. Comparison of Girders.

Fig. 6 shows comparison of the design and weight of a railroad bridge girder, fabricated by riveting together plates of uniform thickness, and standard shapes, with a taper plate welded design of a girder of the same general dimensions, and the same strength, as determined by equivalent moments of inertia. The saving in weight is about 25 per cent.

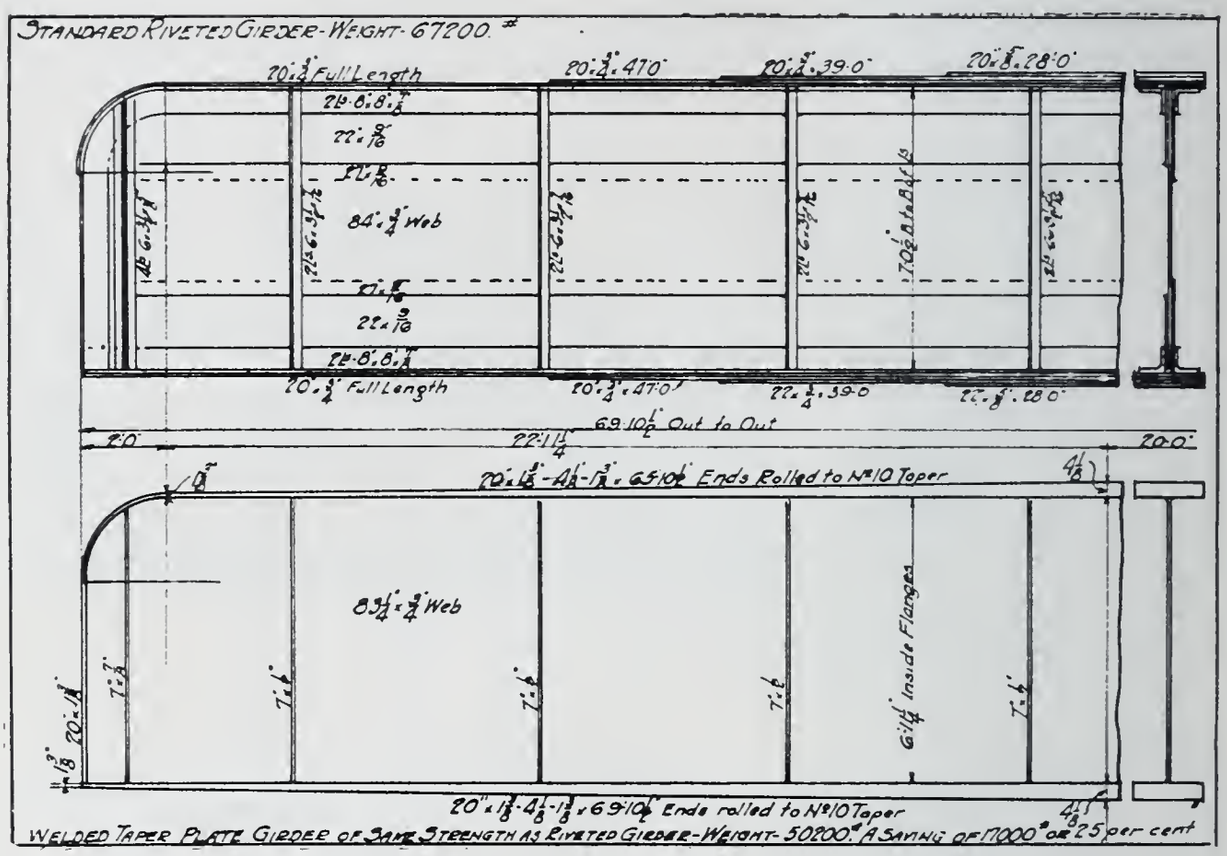

Fig. 6. Comparison of Plate-Girders.

The bridge of which this girder is a part is a half-through, double-track, composite-floor, steel structure, built in 1926, having two main girders 69 feet 10½ inches long, and four tail girders 23 feet 11½ inches long. The girders are spaced 29 feet from center to center, and floor beams are 26-inch Bethlehem girder beams spaced two feet from center to center. The bridge crosses a city street having a 60-foot roadway and two 20-foot sidewalks, on a skew of 25 degrees 38 minutes. A welded taper plate design for the entire structure was made, and disclosed a calculated finished weight of 392,000 pounds against a weight of 485,000 pounds for the riveted structure as built.

When large girders are fabricated by welding, a great reduction in linear feet of welding can be procured by the use of thick taper

plate flanges, as shown in Fig. 6, instead of building up the flanges out of several plates of uniform thickness varying in thickness and length in accordance with stress requirements, the widths of which must also vary to provide room for the welding beads.

The principle of saving weight, and reducing length of welding bead, by the use of taper plates, can obviously be applied to designs of steel ships, steel railroad cars, steel automobile chassis, all machine frames made of rolled steel, etc., in which welding fabrication is employed.

C. S. Davis, *Chairman*: Mr. Duff has given us some very nice questions to think about. The question of economy of design which affects methods of manufacture in the rolling-mills is not strictly relevant, and I think we should confine ourselves to the welding side of the question. If anyone wishes to ask any questions, we shall be glad to have them at this time.

W. H. McCune:* Mr. Miller made the statement that certain types of cup tests were more applicable to deep-drawn steel than the tensile strength. Of what value, may I ask, does Mr. Miller consider the yield-point and elongation as determined by the tensile test as applying to deep drawing steel?

S. W. Miller: I do not know that I am competent to answer the question. There must be a certain amount of ultimate strength and yield-point for satisfactory results. What they are would seem to me to depend on two things—one the original quality of the material, and one the final quality of the material. If you do a good deal of cold work on deep-drawn material, you will have different physical qualities from those that you would have if the vessel were annealed after drawing. I do not think I should want to say in any general way what effect the yield-point and elongation would have on deep drawing material; but I think we are all more or less liable to put a false value on the various physical properties of materials. For instance, why do we have certain specifications for structural steel? Is it because we have deliberately determined that we must have those properties in order to design our structures? Not at all, in my

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opinion. We have found by experience that the material has stood up in a structure; for instance, a bridge. We desire to build another bridge, maybe of somewhat different design. We have found by experience that the first bridge stood up, gave no trouble from distortion or breakage and stood the wind and weather. What do we do? We try to get some material just like the material in that bridge that has given us such good service. How do we find that material? We cut some pieces out of the bridge and find its ultimate strength and its yield-point, and determine its elongation, and we may get the reduction of area. We ask for chemical analysis. We then use those figures for the steel manufacturer to furnish us material that is just like the other material—not because it has any certain physical properties. That is the way we do all our designing. In my judgment, specifications are used solely for the purpose of obtaining material just like what we had before. We do not use any of those physical properties in the designing of our structure. Of what use to an engineer is elongation, or tensile strength, or yield-point? He never uses them. What we do is to depend on our experience and get material that is like what we have found by experience is giving us good results.

I would apply that to Mr. McCune's question. We require the Erickson test not because it is a definite measure of anything, but simply because we know material that has met its requirements can be successfully deep drawn.

E. W. Forker:* I should like to ask Mr. Miller what the practical limits are as to thickness for acetylene welding and whether that limit is due to difficulty in making the weld or due to other considerations such as trouble in getting and handling the heavy plate.

Assuming that we are going to have boilers with very high pressure, say 600 pounds and above, does the author think the tendency will be toward very heavy plates of ordinary low-carbon steel or to the use of special alloy steels with very much higher tensile strength.

S. W. Miller: I do not think there is any limit to the thickness of material that can be welded by any process. I will admit without argument that to-day we have not carried out the welding process

*Hammer Weld Department, Blaw-Knox Co., Blawnox, Pa.

beyond certain limits; but within the period of my own recollection it would have been considered impossible to weld a tank five feet in diameter, 1¼ inches thick and 40 feet long to stand 300 pounds working pressure. When I started welding, it was considered almost foolish to suggest welding plate ⅝ inch thick, but, as the demand for welding increases because of its ease, its strength, its uniformity of thickness of shell and other manufacturing advantages as far as boilers are concerned, so will the demand be satisfied. By one process vessels are now being welded five inches thick, six feet in diameter and 40 feet long. They have been very successful. While I do not doubt they could be made by gas welding, the cost at present would be very high.

The other point is an exceedingly important one. Ultimately, steel of higher strength will be required, because of the expense of weight and the difficulty in welding of the thicker materials of lower strength. It is perfectly possible to-day to make welds of 120,000 pounds ultimate strength, but where are you going to get the plate for that? It is not a commercial proposition. Some say it will follow the same line as has been followed in the development of the large H-beams for columns. The demand came for that and the demand was met; so I put no limit whatever on the possibilities of any form of welding, except commercial ones, and I would say that in the future we will be welding materials of 150,000 pounds tensile strength with no more difficulty than we now have in welding material of 70,000 pounds.

H. S. Ayres:* Can the edges of a universal mill plate be welded without being chipped? Does the mill scale make any difference in the weld?

F. P. McKibben:† It can be welded.

L. E. Endsley:‡ I can not add anything about welding but I can see the possibilities if weight of freight cars can be saved by welding. Then a railroader could afford to pay $500 a car more for a saving of 6000 pounds in the weight of a car and make money on it.

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†Consulting Engineer, General Electric Co., Black Gap, Pa.

‡Consulting Engineer, Pittsburgh.

It means $25 to $30 a year to haul around a ton in dead weight. By saving that much you could pay good interest on the $500 extra cost, and the ability to haul that much more freight would be a gain.

F. P. McKibben: I suggest that we weld one and see.

S. W. Miller: I might say that they have welded cars which are running to-day, and there is no question that the economy of transportation in welded cars is one of the vital questions before the country at present. You will see the time when all freight cars will be welded.

F. J. Giroux: In Europe on apparatus for chemical industry they find that by welding as compared with other methods they save 30 per cent.; on cylindrical construction 15 per cent.; on pipe 20 per cent.; on rectangular hoppers 30 per cent.; naval building, tank steamers, etc., 10 per cent.; railroad car castings, 15 per cent.; framework for electric machines 40 per cent.

C. S. Davis, *Chairman*: It is rather hard to compare methods of doing work there with those here and necessarily so on account of their expensive labor. I do not believe that information obtained from there would be of very great assistance in this country. It might be. Have you any definite information on that, Mr. Miller?

S. W. Miller: I have not. I do not think the cars that have been running have been in service long enough to give it. The railroads that own them have the information, but as far as I know they have not given it out. There are not very many of these cars; but I remember distinctly that a gondola car was built by welding at least 15 years ago and up to the last I heard of it it was giving good service. Those who are familiar with railroading know the difficulty of tracing the performance of cars. Cars are interchanged all over the country and one may not get back on its own line for a year or two. Please do not forget this, either, that the design of welded work, particularly for cars, has to be radically different from that for riveted construction as they are built at the present time, and that it takes time to get the information as to the savings effected.

Another thing we have to consider in the manufacture of railroad equipment, is the large plants designed to make railroad cars by riveting. Can they afford to scrap those plants, or even a considerable part of them? That is a practical condition that has to be met and it will take time.

C. R. TEXTER: Mr. Giroux exhibited several slides showing a weld in relation to the parent metal which had been subjected to acid corrosion. I want to ask what conclusion was drawn from that test. In the 1928 *Proceedings of the American Society for Testing Materials,* Committee A-5 reiterated a statement made in 1907 which was that it disclaims any recommendation of the acid test as a measure of natural corrosion. Subjecting a ferrous metal to the acid test would probably dissolve it entirely in a few hours, whereas the metal would actually last 50 years or more in service. Furthermore, if the metal in the weld were electropositive to the parent metal, corrosion of the metal in the weld would be accelerated, while if the parent metal were electropositive that would be corroded; therefore exposure to any corroding medium would be no indication of the relative resistance of either the parent metal or the weld metal.

F. J. GIROUX: The main thing I want to bring out is that by using a coated electrode there is deposited a metal with greater resistance to corrosion. By using a bare electrode you get a cast-iron deposit. Welds made with certain coated electrodes have a tensile strength nearly as good as you get in steel.

C. R. TEXTER: Are there other tests where the weld corroded first?

F. J. GIROUX: Yes, but I do not have the slides.

C. R. TEXTER: Did you mean to say cast-iron?

F. J. GIROUX: It has practically all the characteristics of a low grade of cast-steel.

F. P. MCKIBBEN: I take exception to the statement that the deposit of a bare metal electrode is cast-iron or has anything like the

characteristics of cast-iron. As evidence that it is not cast-iron, I wish to point to a list of welded structures—more than 100 in number—some of which have been carrying traveling cranes for 11 years, and in the total 100 there has been only a partial failure in a welded joint. If the deposited material were cast-iron, it certainly would never have stood those tests.

S. W. Miller: Professor McKibben has stated it from a practical standpoint. I would also like to say a word in defense of the bare metal electric welding. Good bare-wire arc welding has a tensile strength of 45,000 pounds and an elongation of five per cent. Cast-iron, as it is usually employed, barring special mixtures, has an ultimate strength of 20,000 and an elongation of 1/10 of one per cent, so that cast-iron can not be compared with an electric weld. I do not think it is necessary to stress the qualities of a bare-wire arc weld as being those of cast-iron. It is admitted that it is not as good, in some respects, as those made by other processes; but it is like a good many other things. There are millions of nailed wooden boxes used to-day, though their physical properties are comparatively low. If you need high quality, use the wire that will give it to you. If you do not need it, there is no use in going to the extra expense.

W. H. McCune: As a member of Committee A-5 of the American Society for Testing Materials I would like to indorse the statement of Mr. Texter in regard to the acid test being no criterion of corrosion.

J. P. Toler:* Is any information available concerning the welding of manganese parts? For instance, where manganese is used as in crushing machinery after parts are welded, what values have they as compared with the original value? Does the metal deteriorate after the welding? I should appreciate any information on that subject.

C. S. Davis, *Chairman*: There is work being done in Pittsburgh of similar character to that. Dredging dippers that are being used in the river have their teeth renewed with welding material. That has

*Pittsburgh Limestone Co., New Castle, Pa.

been going on steadily for quite a long time. I might ask Dr. McKibben if he knows anything about it.

F. P. McKibben: No, I do not.

S. W. Miller: I presume Mr. Toler refers to steel containing about 12 per cent. manganese, and the so-called manganese steel about 1½ per cent. carbon. That is a peculiar material. Those of you who have worked with steam-shovels probably know that while it is of comparatively little value in sand digging, it is of great value in rock digging. The reason for the peculiarity is that the manganese steel, which is in an austenitic condition, is changed by the shock in rock digging into martensite, which is the same as a tempered chisel, hard and brittle. That hardening occurs only on the surface, maybe 0.01 inch deep. As that wears off, the hard surface is renewed. You can not cut or machine it, though it is exceedingly ductile and will give an elongation of 100 per cent. in a test-piece. When you heat that metal by any means you change its structure. This was originally brought into an austenitic condition by heating it up to 2100 or 2200 degrees and quenching rapidly. If you heat it and allow it to cool slowly, you have lost the austenitic condition. Another thing is that there sometimes develops an intergranular brittleness which is of no material importance where the material is not subjected to direct tensile stress, as it is not in a dipper. In a rock-crusher you probably would not get satisfactory results after welding. As far as welding a rail is concerned, the same general condition exists. The results depend almost entirely on the service undergone after the welding.

M. J. Holleran:* I might ask about six jobs of electric welding on three portable vertical boilers. Those six jobs were done by three companies around Pittsburgh and all six jobs were failures. All of these jobs were originally welded at the factory and performed satisfactorily for about two years. All six repair jobs fell down in a few weeks. After the flues were welded we had to cut them out. All the repair companies made excuses. On the last two jobs, I put a boiler maker in ahead of the welder, but in every case the work failed. It was so marked that we have definitely given up any repairs of that character.

*Master Mechanic, Booth & Flinn, Pittsburgh.

S. W. MILLER: Do I understand that this was the welding of flues into a flue-sheet?

M. J. HOLLERAN: Yes, particularly on the bottom sheet of vertical boilers.

S. W. MILLER: I know that railroads to-day could not get along unless they welded flues into the back flue-sheet. Practically every locomotive has the flues welded, at least the bottom of the flue-sheet and usually all over. Frequently they would run beyond the three-year limit of the Interstate Commerce Commission when they have to come out.

I do not know anything about the capabilities of the men doing the work. Probably it was overhead work, which is not as easy, with any form of welding, as it is to weld downward. It is very possible that those who were doing that work were not competent to do it. Before I would have those men do any welding, I would find out whether they could weld overhead in a flue-sheet. If they were not able to do it they could not work on the boiler. There again is the point of the qualification of the welder on the job.

M. J. HOLLERAN: That brings up the question again, how to determine qualification. The men that did the work were not 100 per cent. engineers; they were with a commercial company. The tubes did not fail immediately. They lasted a week or two, but they were not a permanent repair. I did not have any test I could apply except the welder's word that he had the best men in town.

R. C. WALDIE:* Charcoal-iron tubes are generally used in steam-shovel boilers. Would there be any difference between the welding of the charcoal-iron tubes and the steel tubes?

M. J. HOLLERAN: These were steel tubes. One item might have had something to do with it. Most of those flues had a copper ferrule. Whether that made any difference in welding I do not know.

S. W. MILLER: The railroad practice is to put the flues in exactly as if they were only to be rolled and beaded, using the usual copper ferrule. The bead, however, is turned over beyond the copper

*Williams & Co., Pittsburgh.

ferrule as a regular practice even if they are not welded. In a properly set flue, the ferrule does not stick through far enough to come out against the flue-sheet. A very little bead is just run around that, sometimes not 1/8 inch wide, so you get penetration into the flue-sheet and also just enough around the flue to hold it in place. If that work is done properly, it will last a long time. There might be other conditions there that are not known. Maybe lime was in the water that got in around the flues and came out during the welding. They probably put on too large a bead. Since the early days, the railroads have had no trouble in getting that work done satisfactorily. On all six of those failures, I think the chances are that the welders could not weld overhead.

M. J. Holleran: When these flues failed, I was always called in right away. Another condition was the fact that the current used may not have been heavy enough. They were all small portable outfits driven by gasoline motors. I do not know what were the characteristics of the current.

C. R. Texter: I do not like to impose upon Mr. Miller but I would like to ask another question. Pipe manufacturers sometimes find it convenient to furnish plain-end pipe of either Bessemer or open-hearth steel for the same pipe-line. In such cases it has been reported by some welders that difficulty was experienced in welding Bessemer to open-hearth steel. In Mr. Miller's opinion should one anticipate any difficulty in welding a length of Bessemer steel pipe to a length of open-hearth steel pipe?

S. W. Miller: In that particular case, it would be very interesting to know where the failure occurred and what the difficulty was. I have welded both Bessemer and open-hearth pipe myself. I should not want to say that pipe material of any kind, as ordinarily made, is the best welding material, but I do not recall ever hearing of any trouble that could be attributed to the type of steel.

P. S. Monk:* We have used electric arc welding to some extent on repairs to city bridges. For instance, we have welded splice-bars across deteriorated places in eye-bars and other tension members of trusses. We have also reinforced floor beams and stringers by

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welding additional cover plates or additional flange angles to the flanges of the old beams. This work has been very successful and has been done at a small fraction of the amount which it would have cost to renew the defective parts. The Bureau also has under consideration the question of securing a water-tight floor on deck bridges with buckle-plate floors by welding the joints.

C. S. Davis, *Chairman*: One point occurs to me in connection with strengthening old work. We all know that no matter how low the stress in the member is, it has elongated. It takes a certain unit stress to elongate a member a certain amount. If we apply additional material by welding without taking the stress off the original member we are not going to be able to work our added material up to the same unit that we are working the material that we are repairing. There will always be a differential between the two stresses, that in the original member and that in the added material, equal to the stress that was in the original member to start with. I bring that up as a point that should make every engineer cautious in repairing old work. He must allow for that differential in stress or he must remove the stress from the member before he repairs it.

F. T. Llewellyn:* The chairman's caution is of course applicable no matter whether the reinforcement is welded or riveted. There is one point that should be watched in reinforcing work, particularly in railroad bridge work, and that is not to try to make a weld while a train is passing over the bridge.

C. S. Davis, *Chairman*: There has been some railroad work done in this vicinity recently, but that consisted of repairing members that were loose. They were diagonals toward the center of the structure and they had either been overstressed or worn in the pin holes or through some other force been elongated and were loose. It was necessary in tightening these to put in new material with turnbuckles. There the reinforcing was put in sufficiently strong to carry the entire load and after the new material was applied, the old bar was cut in two so that there was no question as to distribution of stress. I really think that reinforcing railroad bridges is being properly done as most railroad bridges are in the hands of competent engineers.

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WASTE HEAT IN THE STEEL INDUSTRY*

By George R. McDermott†

The purpose of this paper is to present to members of this Society certain general aspects of the available sources and methods employed for the recovery of waste heat in the steel industry.

Waste heat may be defined as the total heat remaining in the combustion gases after they have performed their primary function in the furnace. It is sometimes called "stack loss." The total heat loss consists of sensible, potential, and latent heat. Sensible heat is the heat carried by the gases due to the temperature difference between the incoming air and the outgoing stack gases. Potential or undeveloped heat is the heat available as unconsumed gas. Latent heat is the heat of evaporation of any water present in the flue-gas.

The principal sources of waste heat in a steel plant are the waste gases from metallurgical furnaces, gas-engines and boilers.

Metallurgical furnaces offer one of the most profitable sources of waste-heat recovery. Furnaces with regenerative or recuperative devices for preheating the air for combustion have from 30 to 55 per cent. of the total heat available remaining in the stack gases. Furnaces without such provisions for preheating the air may have as high as 80 per cent. of the total furnace heat input escaping from the stack.

To determine the available waste heat of a given furnace for purposes of preheating the air or for boiler utilization, the most accurate method is to run a complete heat balance by the accepted methods. At times it is neither convenient nor practical to do this and sufficiently accurate results may be secured by ascertaining the fuel consumption, the temperature and analysis of fuel and the temperature and analysis of the waste gases leaving the furnace. Charts of the sensible heat contained in the waste gases, air for combustion, and the gas itself at various temperatures are very useful in simplifying furnace calculations.

Cost is the primary consideration in the installation of air preheaters and waste-heat boilers and economizers. The installation may be justified from the standpoint of fuel economy and not from

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the standpoint of cost. The equipment, of course, should yield a satisfactory monetary return on the investment and not require excessive supervision and maintenance. Local conditions and equipment dictate the limit to which waste-heat recovery should be carried.

In the application of recuperators and air preheaters to metallurgical furnaces there are certain physical limitations as to the degree of preheat which it is practical to use, and these are inherent in the nature of the heating processes themselves. Too highly preheated air may produce a flame with characteristics unsuited to the heating process. The flame may be of too high a temperature and its rate of combustion may be too rapid. Again, with certain fuels, it is practical to use a higher degree of preheated air than with others because of the chemical composition of the fuel, especially as regards the hydrogen content and luminosity properties. A further consideration is the kind of material being heated. If the material is of a large section, the rate of conduction of heat from the surface to the center of the material becomes the limiting factor and often precludes the possibility of using the maximum preheat attainable. In this connection we have found from practice that, although limited in the degree of preheat which can be successfully used for a particular type of heating furnace, there is 15 per cent. heat recovery which, expressed in fuel costs, represents a return of 68 per cent. on the installation of the recuperator, including interest and depreciation on the investment.

The preheated air effects two major economies, first by the saving of some of the sensible heat of the waste gases and second by producing a higher flame temperature which gives a greater heat transfer due to a higher heat head and luminosity of flame. A further saving of heat is provided in that it is possible with preheated air to burn the fuel completely, using less excess air. This effects a large saving in costs by decreasing the scale loss.

The installation of boilers for utilizing waste heat from metallurgical furnaces has great economic possibilities. A number of papers have been presented on this subject, and what I submit at this time will be more or less a repetition of what has already been presented. However, on account of the large savings that have been effected by such installations, I perhaps will be pardoned if the subject is again brought to your attention. There may be some of you who are dealing with the problem at present and, if so, I hope that a discussion of the

subject will be of some assistance in arriving at a correct solution of your particular problem.

Air leakage between furnace port and boiler heating surface is the source of appreciable loss in efficiency and it is necessary to give considerable effort to keeping the brick settings tight. Frequent blowing of tubes is necessary on account of the exceedingly fine and adherent dust which is carried by the gases leaving the open-hearth furnace.

The weight of gases leaving the open-hearth furnace in particular is difficult to determine. For a specific illustration of the method of computing this item, reference is made to an example of an open-hearth furnace calculation, which appeared in a paper, entitled "Waste Heat Utilization for Steam Generation," presented by the author before the Association of Iron and Steel Electrical Engineers in 1921.*

The subject of heat transmission and boiler design may be discussed from the standpoint of rate of heat transfer as determined by the degree of mean temperature difference between the available gas temperature and the steam, clean surfaces, and relative gas velocities in or across the tube-heating surface. On account of the relatively low gas temperature it becomes necessary to resort largely to the laws of heat convection for economic heat transmission.

The rate of heat transfer for either fire-tube or water-tube boilers may be expressed in the equation $R = a + b\frac{W}{A}$, in which

R = heat transfer rate in B.t.u. per hour per square foot of heating surface per degree difference in temperature.

a and b = constants.

$\frac{W}{A}$ = mass velocity expressed as pounds of gas per square foot of gas passage area expressed in square feet.

As a general rule, the constant a is greater for water-tubes than for fire-tubes of the same size; greater as the diameter of the tube decreases; and greater as the space between water-tubes decreases.

Similarly, the constant b is greater for water-tubes than for fire-

*Proceedings of Association of Iron and Steel Electrical Engineers, 1921, p. 357-402.

tubes; greater as the diameter of the tube decreases; and greater when the temperature difference between steam and water increases.

While with the Illinois Steel Company, South Chicago, the author made his first studies and first successful application of a boiler installed for the utilization of waste gas leaving an open-hearth furnace, for steam generation. Many of the later installations, both of the fire-tube and water-tube type, were designed and laid out based on the experimental and practical information obtained therefrom. It was in that plant that the fire-tube type was first developed. The reason for this departure was simplicity of construction, adaptability to efficient recovery of heat largely by convection, ease of maintaining proper operating conditions for economic steam production, and low operating and maintenance costs.

Referring again to the general formula it is of interest to note that, as the area of the gas passage decreases, the value of R increases. This is also true as the diameter of the tube decreases in value; for example, a increases from 1.1 to 3.5 by using four-inch tubes instead of one-inch tubes.

As has been stated before, the heat absorption is largely by convection, and for that reason it becomes necessary to pass the gases over the heating surface at or above their critical velocity. This is attended by an increase in the draft loss due to increase in frictional resistance of the tube wall, also influx and efflux losses of gases entering and leaving the tubes.

The first fire-tube boilers were built vertically. They consisted of two passes, and had flues three inches in diameter. Later, successful single-pass horizontal boilers were built, made possible by the use of two-inch and 2½-inch flues. The rate of heat transfer was increased by the use of the smaller diameter of flue and thereby confirmed the above formula and constants obtained by experiment.

The question has often been asked as to what is the minimum temperature at which it would be profitable to install a waste-heat boiler. This, of course, depends on local conditions; however, as a general rule the temperature is in the neighborhood of 800 degrees F. provided also sufficient gas weight is available.

As a general rule, the installation cost is 15 to 20 per cent. greater than that of an ordinary coal-fired boiler with equipment for handling coal and ashes. However, this is due to the building of flues

to meet existing conditions, changes in buildings, etc. If the installation is made at the time the open-hearth plant is built, then it is likely that the system can be built at a reduced figure.

The recovery of heat in the waste gases from soaking-pits and heating furnaces also provides a fertile field even after the installation of apparatus for preheating the air required for such furnaces. As pointed out, when discussing the subject of preheated air for heating furnaces, it is not always possible to use the degree of air preheat that it is possible to obtain, due to the particular heating requirements. In such an event, a waste-heat boiler may be installed to utilize a portion of the waste gases direct as they leave the furnace downtake.

As an example of what might be accomplished along these lines, the author at one time investigated the economic possibility of installing waste-heat boilers in connection with a battery of 10 regenerative soaking-pits. By combining the waste gases in three groups, calculation demonstrated that sufficient gas weight and temperature were available to develop 1100 boiler horse-power based on 90 per cent. operating time. Such an installation indicated a return on the investment of 45 to 50 per cent.

Another field, which may develop in this country when economic conditions warrant it, is utilization of the exhaust of large gas-engines. To this field, the fire-tube type of boiler lends itself very nicely on account of limited space requirements, the use of flues of small diameter, and the power available to force the gases through the tubes at high velocity developed at a relatively high thermal efficiency.

DISCUSSION

W. C. Buell:* I had hoped to discuss Mr. McDermott's paper at length, but there are two reasons why I can not do so. The first is that I did not see the paper until shortly before I came to the meeting this morning, and the second is that the paper is rather general in its scope. I dislike to offer specific comment on casual statements. However, there are some figures included that will bear discussion and I will touch upon them.

He speaks of a stack loss of 80 per cent. in a metallurgical furnace, the furnace being of a type without heat-salvage apparatus. While such a loss might be possible in a small furnace used for weld-

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ing, or a similar unusual operation, it is not and can not be taken as representative of reheating or lower temperature operations. With 80 per cent. of the sensible heat in the waste gas, the temperature of the waste gas will be greatly in excess of any temperature required in industry other than for metal melting, unless there is the inclusion of a considerable volume of excess air. With natural gas and no excess air, the stack gas with 80 per cent. of the total sensible heat still included would have a temperature of around 3200 degrees F.; while, if 25 per cent. excess air is assumed to be included, the temperature of the waste gas would still be above 2500 degrees F. These temperatures are quite high for metallurgical practice and are seldom realized without preheating of the combustion air.

To consider another fuel—raw producer gas—in the same way, the furnace gas containing 80 per cent. of the sensible heat and no excess air would show a temperature around 3000 degrees F. and, with 25 per cent. excess air, about 2800 degrees F. With this fuel, these temperatures are unobtainable without preheating.

In periodic furnace practice, it is axiomatic that the furnace gas enters the downtake at or above the temperature of the burden, which in reheating practice seldom exceeds 2200 or 2300 degrees F. At these figures, the total sensible heat in the gas entering the downtake is perhaps 55 or 60 per cent. of the total which would seem to represent a better figure of general practice than Mr. McDermott's figure of 80 per cent.

In recuperative practice, he speaks of a 30-55 per cent. final stack loss. These figures also appear much too high to be representative of general practice. With natural gas, they indicate temperatures of 1250 to 2250 degrees F. and, with producer gas, 1200 to 2100 degrees F. with excess air from zero to 25 per cent.

Assuming intelligent design and installation of the heat-salvage apparatus, and ordinary operating conditions, it is unbelievable that an engineer would concede these figures as representative of modern recuperative practice. In my own practice, 20 to 30 per cent. covers the ordinary range.

G. E. Dignan, *Chairman*:* Perhaps Mr. Kells, who read the paper in the absence of the author, would care to reply.

*Chief Engineer, Rust Engineering Co., Pittsburgh.

L. R. KELLS:* I am in the same position as Mr. Buell. I found out yesterday afternoon that I had to read the paper this morning and I had not seen it. However, I believe the example Mr. McDermott referred to when he was speaking of the 80 per cent. was in a simple type tube-welding furnace where temperatures are quite high. I am not prepared to answer the question in regard to the percentage, but Mr. McDermott will be glad to do that by correspondence.

W. F. KEENAN, JR.:† As a matter of interest in connection with the last paragraph where the possibility of utilizing gas-engine exhaust is referred to, we have recently been working on a proposition in connection with Diesel-engine exhaust where the apparatus for waste-heat recovery is combined with the muffler design. The deterioration of mufflers is a problem in Diesel-engine work and by combining waste-heat recovery with muffler equipment and making it of all cast-iron construction, it is hoped that it will be possible to kill two birds with one stone.

C. A. CARPENTER:‡ There is one problem in connection with heat from gas-engine exhaust. A great deal of effort has been expended on the generation of steam from waste heat. In several cases of industrial application, steam is generated for such uses as heating. It is frequently possible to use both jacket water and waste-heat recovery devices for heating buildings. I once had to make a lay-out of that kind for an industrial plant. The installation was never made, but the theoretical figures indicated a very considerable saving, by utilizing waste heat directly for hot-water heating of buildings.

J. A. DENT:§ If I understood correctly, it was stated that when air is preheated for use in these furnaces a more complete combustion could be obtained. I would like to point out two conflicting factors there. For moderate temperatures, that is perfectly correct; but, with very high temperatures, the point of chemical equilibrium is reached, beyond which it can not be carried. That is even with ideal conditions. Combustion can not be made complete at very high tempera-

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tures, so that there will be a limiting point beyond which preheating of air will not improve combustion.

W. C. Buell: I should like to comment on Professor Dent's remarks. In metallurgical practice, we secure our highest temperatures by the use of highly preheated air. In manufacture, the highest temperatures (from fuel) are found in the open-hearth furnace. The gas temperature sometimes approaches 3500 degrees F.; it frequently reaches 3200 degrees F. and the air is heated to 2000 degrees F. or more. Up to this point, chemical equilibrium is not a factor for, to this point at least, it becomes easier to maintain a more nearly complete combustion with a very rapid flame development.

Personally, I do not think that chemical equilibrium becomes a factor within out present temperature range in constant-pressure work. I know it is a very considerable factor at much lower temperature, and has been given much study in constant-volume practice and theory. So far, the only factor that has limited preheat temperature in combustion practice has been the failure of refractories from the resulting excessive flame temperatures.

J. A. Dent: May I say another word as to that incomplete combustion at the highest temperatures. If the gases continue over the bath to be heated, the combustion will not be complete at the highest temperature. As the gases approach the stack and the temperature falls, combustion tends to complete itself. We may, therefore, have a stack analysis indicating complete combustion, although the heat is not completely developed over the bath, and the flame temperature would be somewhat less than that calculated on the basis of the analysis of the stack gases.

W. C. Buell: Theoretically, Professor Dent is undoubtedly correct in his premise; but we all know that every now and then theory and practice do not interlock.

About fifteen years ago, I was working actively in combustion research. At one time I made a considerable study in flame development with preheat temperatures running up to 2400 degrees F. Both fuel-oil and natural-gas fuels were used. My experimental furnace was so designed that gas samples could be drawn and temperatures

taken at six-inch distance in the flame itself, which could be adjusted to any length up to six feet. The ease of maintenance of perfect combustion and the rapidity of flame development progressed appreciably as the preheat increased and at no time was evidence seen of any retrogression due to approaching chemical equilibrium.

J. R. Mason:* I wish to bring up the question of cleaning the gas side of the heating surface in waste-heat boiler installations, more particularly in connection with open-hearth furnaces and cement-mills, and thought someone might be able to make a helpful suggestion along this line. This problem seems to be a source of trouble to a great many people who have waste-heat installations, more especially those who have boilers installed where there is a large draft loss through the boiler. This applies to both bent-tube and straight-tube boilers, and being able to keep the heating surface clean is one of the big factors in successful operation.

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MECHANICAL DRAFT IN THE CEMENT AND STEEL INDUSTRIES*

By G. C. Derry† and J. R. Darnell‡

In cement-mills and steel-mills, induced-draft fans are subject to very serious erosive conditions and must be designed to withstand the severe abrasive action of cement dust and other materials. In steel-mills, the induced-draft fans must frequently handle flue-gas from the combustion of dirty or poorly washed blast-furnace gas which contains abrasive material. It has been generally considered that for this duty the fan wheel should have blades of the straight radial type. Among fan engineers such fans are called "steel-plate type." They also are sometimes classed as the "paddle-wheel type." Incidentally this is the oldest type known and was first built by Mr. B. F. Sturtevant some sixty-five years ago when the fan business started. Mr. Sturtevant was previously engaged in the manufacture of shoes—an industry in which dust was present to such an extent as to constitute an industrial hazard. The laws at that time were naturally not so severe as now but the dust made it very uncomfortable for the workmen and so Mr. Sturtevant, with Yankee ingenuity, started to work on a fan which would remove this dust. With the increasing demand for fans he conceived the idea of making this his regular business, and thus started the original fan company. It is interesting to know that the original line of steel-plate fans as developed by Mr. Sturtevant still remains one of the most efficient on the market.

These fans usually run at speeds which are so low that an accumulation of dirt and dust on the wheel does not cause vibration, or unbalancing. The passages between the blades are large and any deposit will be so thin, comparatively, that there will be no appreciable loss of capacity or efficiency. The possibility of dirt accumulation, however, may be a serious factor in the operation of fans of the multi-blade type, particularly those with the full forward curve.

Recent developments in fan design lead us to believe that we have something better to offer both the cement industry and the steel industry, for induced draft, than the conventional steel-plate fan.

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We shall later discuss this fan in detail. We, however, experimented with various designs before we finally developed our present construction for use in cement-mills. These fans are essentially the same as most steel-plate types except that we bind the inlet edges of the blades with half-round iron to minimize erosion at this point. We also fasten the blades to the side sheets by means of heavy angle-iron, and all rivets are countersunk. Finally we put a wedge-shaped piece of sheet-steel across the back of the blade at the tip, instead of the usual stiffening angle. This allows dust and dirt to slide off easily instead of accumulating under the angle (See Fig. 1).

Fig. 1. Fan for Cement-Mills.

We have a number of installations which were in operation more than a year before repairs of any kind were necessary. One plant was in continuous operation 42 months. Previous to this, many installations were in service but a few months, owing to abrasion.

Fig. 2. Results of Abrasion.

In Fig. 2 are shown two bolts which indicate the effects of abrasive material in flue-gas. The smaller of the two has been worn by cement dust and the other by powdered-coal ash. In the case of the bolt in the cement fan, the nut, which was on the inside of the housing, was completely worn away. With the powdered coal, the bolt was used to fasten an inspection door, being threaded into a piece of angle-iron. For some reason, this particular bolt was too long and that portion

which extended into the housing beyond the angle-iron, was worn down as shown.

At a certain large cement plant, for the past eight months, an experiment has been made with a steel-plate, induced-draft fan. Observations are being made on eight blades. Two opposing blades are of "Ascoloy," two of "Atha" steel, two of ordinary mild steel, and two of mild steel coated with "stellite." We intend to make an inspection of these fans in the very near future.

We have conducted extensive research to find metals or other materials which would stand up against abrasion. Many alloy steels were tried out in our laboratory but we very soon discovered that the harder the steel the greater the abrasive effect. This, we believe, is due to the fact that as the abrasive particle travels over the steel it chips the hard metal off and carries it away, while with the soft steel it merely makes a groove as a plow goes through the land. We have also tried rubber, leather belting, and copper, and have even thought of trying glass. Of course, some of these materials are immediately prohibited because of the temperatures under which they must operate. The subject has been given considerable study and most of the prominent engineers to-day have decided that they must put up with the situation and have spare wheels on hand for replacement when necessary.

In general, "Ascoloy" steels contain less nickel and more chromium than "Atha" steel, the relative proportions in the former being approximately reversed in the latter. All of these alloy steels are non-magnetic.

"Stellite" alloys in general are composed of chromium, cobalt, and tungsten and do not contain any iron except as impurities. "Stellite" is applied to steel surfaces with an acetylene torch but is not particularly easy to work and to get a satisfactory result, the services of a man skilled in welding are required. This process is known as "stelliting." "Stelliting" may prove the best solution of abrasion troubles in induced-draft fans but at present we do not have sufficient evidence to warrant any positive statements. For fans which are already in service and which develop abrasion troubles, "stelliting" is the best remedy of which we have knowledge to-day. In one large central station, where powdered coal is burned, the fan blades were cut entirely through in about five weeks. After the rotors were re-

bladed, "stellite" was applied by the customer at points where erosion occurred and the fans have now been in continuous operation 28 weeks and may be good for that much more.

It seems a foregone conclusion that in practically all cases abrasion is to be expected in fans handling cement dust, whereas fans handling powdered-coal ash may or may not be affected by abrasion. This depends largely upon the quality of the ash and the velocity of the gas. In one plant where powdered coal was burned, erosion was negligible until the speed of the fans was increased. At first the boilers were intended to operate at slightly over 200 per cent. rating, but, later on, it was decided to operate at 300 per cent., or above, if possible. In order to do this, larger motors at higher speed were installed. Increasing the fan speed from 500 to 700 r.p.m. immediately caused abrasion troubles and the blades cut through in three to five weeks. In this case, however, we did not attempt "stelliting" as even the increased speed was not sufficient to give the desired steam generation. Larger fans with greater inlet and outlet areas are now being installed.

Fig. 3 shows an example of "stelliting" on a forwardly curved type of blade. Since "stelliting" is quite expensive, we do not think it advisable to ship out new fans with "stellite" applied to the blades since we do not know definitely at what points erosion will occur, if it does show up at all, and because even similar fans show different points of erosion. We believe it is much more economical and more satisfactory in the long run, to wait until abrasion develops and then have the customer send us representative samples of the eroded blades so that we can apply "stellite" on new blades at the proper points before shipping replacements to the customer or else have the customer watch the action and himself apply the "stellite" as soon as the nature of the abrasion is evident.

It may be well, at this point, to tell you something about the various types of fans that are used for induced draft. Paddle-wheel or steel-plate fans are generally used in the cement industry and also in the steel-mills, particularly for sintering.

Exclusive of these industries, however, there are probably more plants operating with forwardly curved blades in induced-draft fans than with all other types combined. Low price is a great attraction. This may be one reason why induced draft has caused so much trouble and is so often blamed for limiting the boiler output. The greatest

objection to the fan is its extreme susceptibility to inlet conditions. We have seen on our test block, a drop of pressure from seven inches, with an open inlet, to four inches with an inlet box of the customary form and size. For a given duty this type has the lowest tip speed and the highest air velocities leaving the wheel. Inherently it depends for its static pressure on conversion of the high air velocities in the

Fig. 3. Application of "Stellite."

housing, and consequently has the lowest efficiency. Parallel operation with this fan should be avoided, as trouble is almost sure to follow unless the operating conditions which determine the system characteristic, are accurately known. Our practice is to use it only when space limitations require its selection and then only in a single inlet arrangement with a carefully designed inlet box and plenty of excess capacity

in both fan and motor. In one case, following a competitor's design for test purposes, we built a double-inlet, single-width wheel and provided a large diffusing chimney on the outlet. The result, apparently, was such a high efficiency that we were almost startled into admitting that the competitor had done something real. However, after we had plotted the velocity gradients of our traverses, we saw they were so uneven that there was an eddying flow and the readings were unreliable. A nozzle test showed 18 per cent. less volume and brought the efficiency down to normal.

The second type is the steel-plate or paddle-wheel fan about which we have already spoken. This has been a good all-around fan for induced draft but there is no reason why it should not be replaced by a more efficient and more compact type of fan.

For the same duty, the steel-plate fan has a larger wheel and occupies more space than any other type. Consequently, it runs at lower speed which may occasionally be advantageous but is more often disadvantageous, especially where the fans are to be driven by alternating-current motors.

Speed should be given prime consideration with any type of alternating-current motor selected. For any given motor horse-power, the higher the speed the less the cost, since the number of poles required decreases proportionately as the speed is increased. It is advisable, therefore, to select fans which will run at comparatively high speeds. Where operating conditions permit, 1800 or 1200 r.p.m. are desirable speeds for forced draft and 900 or 720 r.p.m. for induced draft.

Occasionally purchasers of fans specify the speed, stating that it shall not be over 1200 r.p.m. (in a few cases, not over 900 r.p.m.). This may be due to some fear of high-speed motors but, if all bearings are kept properly lubricated, the high-speed motor is much more desirable than the low-speed type. When it is realized that a fan must operate at a certain "tip" or peripheral speed to produce a given pressure, it can be readily seen that if the motor speed must be reduced, the wheel diameter must be increased to maintain the same tip speed. The purchaser, therefore, must decide whether he will have a large fan running at low speed or a small fan running at high speed. In most cases, the advantages are all in favor of the small fan. It

occupies less floor space, weighs less, costs less, and the motor (having fewer poles than the low-speed type) will also cost less.

Purchasers will be assured of the best results if they will permit the fan manufacturer to select fans for the highest efficiency, the speed being allowed to remain at the motor speed required.

Even if turbine drive is decided on, the high-speed fan will be more economical. With the slow, paddle-wheel fan, if a turbine is used it can not be direct connected but an expensive reduction gear must be placed between the turbine and the fan.

The slow-moving, steel-plate fan has its best economy only where there are comparatively large volumes and low pressures, and it is desirable to run the fans with engines at speeds not over 450 r.p.m.

The third type is the partially forward-curved blade, radial at the tip. The modern development closely resembles in its characteristics the older paddle-wheel impellers, but efficiency is secured with smaller size and higher speed. These fans operate well in parallel and are good general-purpose fans. Their great advantage is in their suitability for continued successful service in the dust and soot of induced-draft work. There is no tendency for dirt to pile up in any part of the impeller, and thus troubles due to unbalancing are avoided. The fan is not affected so seriously by inlet conditions as the types previously discussed. The ordinary inlet box will decrease its performance 10 to 15 per cent. However, to avoid this loss in our own case the inlet box has been developed as part of the fan, and the characteristic curves determined with the inlet boxes in place. This is the new type of fan, mentioned in the beginning of this article, and we should like to explain some of the more important features.

We believe that, in both the cement industry and the steel industry, this fan will find greater favor than the old paddle-wheel fan. We can appreciate the hesitancy of operators of cement plants or steel plants in this district in accepting a new type of radial-blade fan, when those which they have previously tried have given erosion troubles. It should be noted, however, that until the advent of the Sturtevant "Turbovane I. D." fan, induced-draft fans of every type were provided only with the conventional square inlet boxes. These did not permit uniform distribution of gas to all parts of the wheel, and the result was that at certain points there were high-velocity jets which drove the gas, laden with abrasive material, into the wheel in

such a way that each blade as it passed these points was worn away. Successful operation with powdered-coal ash, which is fully as erosive as cement dust, gives us every reason to believe that the new "Turbovane I. D." fan will replace the old paddle-wheel type fans in most industries.

For years, all fan performance has been based on laboratory tests conducted with fans having open inlets; that is, the air from the room is drawn into the open wheel, or into inlets with long, straight ducts.

Performance data for a fan set up in this fashion are fairly satisfactory in most cases if the fan is to be used for forced draft, but entirely unreliable if intended for induced draft.

For forced-draft practice, the fan is installed in the boiler house in the same way as in the laboratory assembly. In most cases, air is drawn directly from the fan room into the fan and eventually discharged to the furnace; but, if the fan is to be used for induced draft, some sort of duct must be used to connect the inlet of the fan with the gas outlet from the boiler. In many instances, a round, sheet-metal duct, corresponding to the diameter of the fan inlet, is brought up from below and connected to the fan by a comparatively short right-angle bend.

Inlet ducts or boxes entirely change the characteristics of the fan as determined with open inlets, due to the fact that the gas or air can not be evenly distributed to all parts of the wheel. Accurate tests have shown that the gas entering certain parts of the wheel has a forward "spin" in the direction of rotation, while in other parts the "spin" is reversed. Naturally this tends to set up eddy currents entirely different from the smooth flow obtained in the laboratory where open inlets were used. This causes a material reduction in the static or useful pressure which the fan is supposed to deliver and a corresponding increase in power consumption.

Most fan designers were probably not aware of this condition for there is no record of anyone attempting to show the difference between the performance in the laboratory and in the field. That they did realize the inefficiency of directly connecting a duct to the fan of the same size as the inlet is shown by numerous installations where this is modified by using sheet-metal boxes, of substantially larger cross-sectional area than the inlet to the wheel, and which are

attached to the inlet, and the gas ducts then connected to these boxes.

It is true that an installation of this type will give better performance than the one with an ordinary elbow, but there is no evidence that any fan engineer ever made a test performance in the laboratory with an installation of this type which was later duplicated in the field.

To approximate laboratory performance, the static pressure required at the fan should be increased by at least 15 per cent. to compensate for the loss through the inlet boxes, and in some cases 15 per cent. is not nearly enough.

If the fan manufacturer will not guarantee that the induced-draft fans have been tested with the inlet boxes connected to the fans in exactly the same manner as they will be installed in the power-plant, purchasers should insist that the bidder make adequate provision for inlet-box loss by designing the fans for at least 15 per cent. greater pressure than given in the specifications.

We have known of cases where the customer was told that he need not worry about inlet-box loss, inasmuch as the static pressure he was asking for was considerably more than he would really need and, even though there might be loss through the boxes, the static pressure would still be ample. This may be entirely true but we must not lose sight of the fact that, due to the loss through the inlet boxes, the static efficiency of the fan will be at least 15 per cent. lower than stated, and the horse-power correspondingly higher. If the ordinary inlet boxes are attached, the static efficiency of any induced-draft fan will be from 50 to 55 per cent. instead of 60 to 65 per cent. as ordinarily shown with open inlets.

Ordinarily, as installed in the power-plant, it is impossible to test fans according to the accepted test codes, due to the fact that rarely, if ever, is there a straight run of flue from the fan discharge or inlet, equivalent to 10 diameters. If the straight run of discharge is less than this there may be eddy-currents which will cause erratic pitot tube readings, and make calculations of the volume little better than a guess.

Attempts to determine fan performance by calculation of gas volumes based on weight and analysis of the coal and analysis of the flue-gas, are dangerous, and should not be given consideration because of the multiplicity of errors which invariably enter into such indirect

methods of volume determination. It follows that, since it is practically impossible to check fan performance by field tests, purchasers should select induced-draft fans which already have been tested in the laboratory *with the inlet boxes in position*—fans which the manufacturer will not hesitate to test again in the presence of the purchaser's witnesses, if desired.

Besides not making any allowance for loss through the inlet boxes, with the ordinary type of induced-draft fan, many operators fail to consider leakage and air infiltration into the setting. In some cases they miscalculate the quantity of gas by incorrect gas analysis, deceiving themselves into thinking they have high CO_2 and low excess air. From long experience, Sturtevant engineers have found that unless an induced-draft fan is designed to deliver, per developed boiler horse-power, at least 18 cubic feet a minute when measured at 400 degrees F., or equivalent volumes at other temperatures, there is grave possibility that the desired boiler load will not be maintained.

For many years, fan engineers have been guaranteeing field performance of induced-draft fans, based on tests in the laboratory under conditions not at all similar. It was not, however, until comparatively recent times that boilers have been called upon to run at high overloads, and since induced-draft fans were often built much larger than really needed, there was much less serious difficulty than might have been expected.

With boilers being called upon for higher and higher ratings, induced-draft fan installations of the future will not meet expected performance unless proper consideration is given to these points. It seems hardly necessary to point out that with such large expenditures as are found in the building of a power-plant, the induced-draft fans should be the last place to economize, as they usually represent less than one per cent. of the total investment.

Air and gas are really ponderous substances having both mass and weight, and due to the fact that they are so easily compressed or rarefied they must be handled with care and guided in the path they should follow. They follow the line of least resistance and owing to their compressibility are not so easily turned from the direction in which they are flowing as in the case of liquids.

Sturtevant research engineers realized the pressing need for an induced-draft fan with inlet boxes which would not embody mere

guesswork but would be designed to guide the gas into the wheel with the least possible amount of shock. They have now developed such a fan which embodies a number of features entirely new to induced-draft practice. This fan, known as the Sturtevant "Turbovane I. D." is built to handle flue-gas at all ranges of temperature, in particularly large volumes and high pressures, and at high peripheral speeds.

As shown in Fig. 4, this new fan has been designed with special double-scroll inlet boxes. Similarly to a centrifugal pump, which is

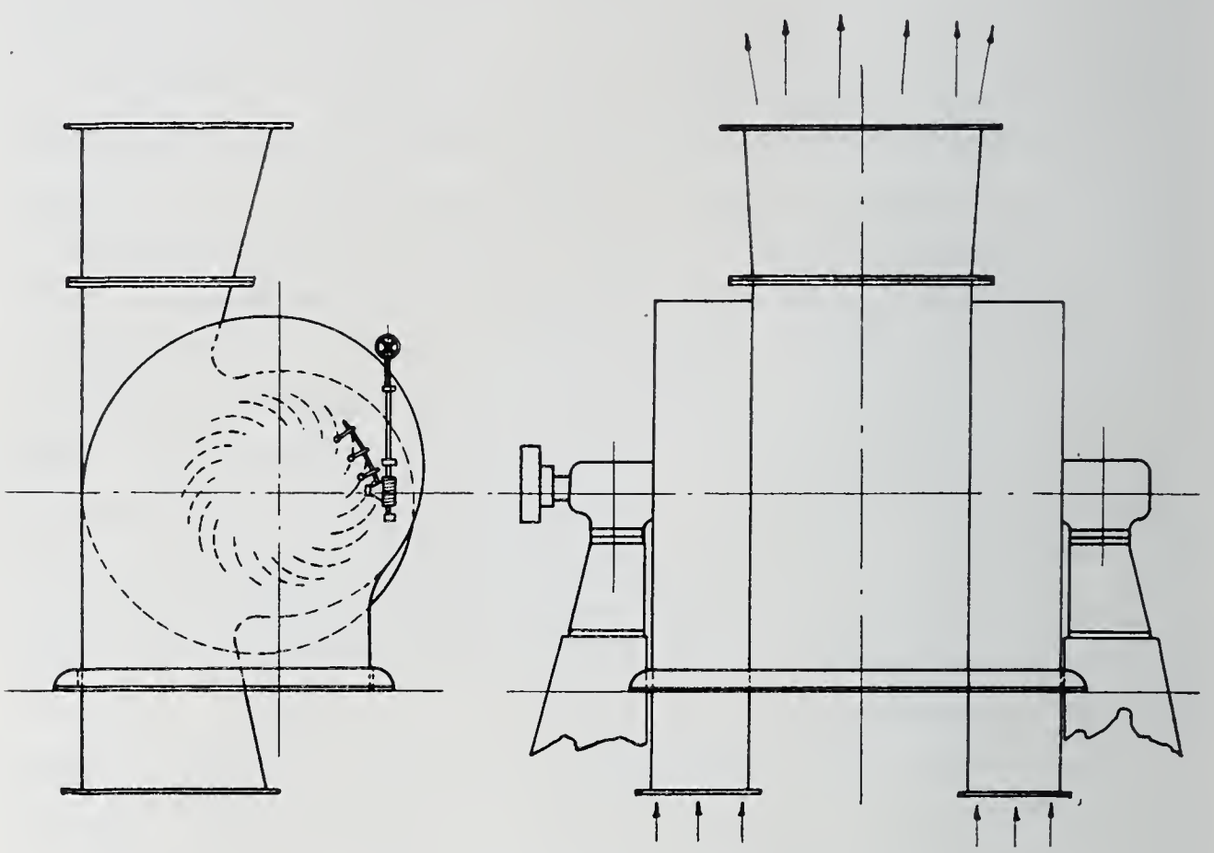

Fig. 4. Fan with Special Inlet Boxes.

of the same family as the fan, inlets and outlet are center-lined. This greatly simplifies the installation, eliminates the ungainly appearance of the conventional square inlet boxes, and results in symmetry and efficiency. When required, the inlet and discharge can be varied independently to any angle while still maintaining the uniplanar line-up of inlet and outlet.

Symmetrical appearance, however, was not the prime consideration in the introduction of the scroll inlets. These were designed to give the gas entering at all parts of the wheel a forward "spin" in the direction of rotation; but it was found that the gas entering the wheel was given so much "spin" that it was traveling faster than the wheel.

To reduce this velocity to the peripheral velocity of the wheel, specially designed inlet vanes were provided within the inlet scroll, and evenly spaced around the inlet to the wheel as shown in Fig. 5. This

Fig. 5. Fan with Special Inlet Vanes.

view was taken from inside the fan housing with the rotor removed. Such an arrangement of vanes insures the fan inlet being uniformly filled with gas.

Here at last, is a fan which will handle flue-gas with the least possible amount of inlet loss—a loss which heretofore has averaged 15 per cent., or greater. Since the scroll inlets and vanes are exactly identical with those to be installed in the field, complete agreement between test and field performance is thus, for the first time, assured.

In the first design, the inlet vanes were provided solely for the purpose of retarding the "spin" of the gas. These vanes were in a fixed position and the volume and pressure controlled by varying the speed. It was subsequently discovered that, if the fans were operated at constant speed, control could be effected by changing the relative position of these vanes, making them open or close by overlapping each other.

With all other types of induced-draft fans, the volume is controlled by one of two methods—it may either be regulated by an ordinary plate or louver damper placed either in the discharge or the inlet of the fan, when running at constant speed, or the volume may be controlled by varying the speed of the prime mover.

If an electric motor be used, it is ordinarily of the wound-rotor (slip-ring) type having a multi-point controller, usually with 13 to 31 points. Both of these methods have been quite expensive. With the former the initial cost, of course, is low, since the constant-speed, squirrel-cage motor can be used, but the resultant horse-power consumption, due to the damper, is high.

With the second method, using a slip-ring motor, the initial cost is high, due to the increased cost of the motor and its complicated control mechanism. Furthermore, the maintenance of a slip-ring motor is expensive and many power-plants will welcome the opportunity for discarding this method of fan control. The horse-power consumption is lower than with ordinary dampering, but is still fairly high, due to the fact that as the speed is reduced the efficiency of the slip-ring motor falls very rapidly.

In Fig. 6 is shown a typical comparison between the efficiencies of constant-speed and slip-ring motors. The upper curves (A and B) are for a synchronous motor and squirrel-cage motor respectively. Either of these constant-speed motors has practically a flat curve of efficiency for ordinary loads, which are seldom under half of full load, or over 1¼ of full load.

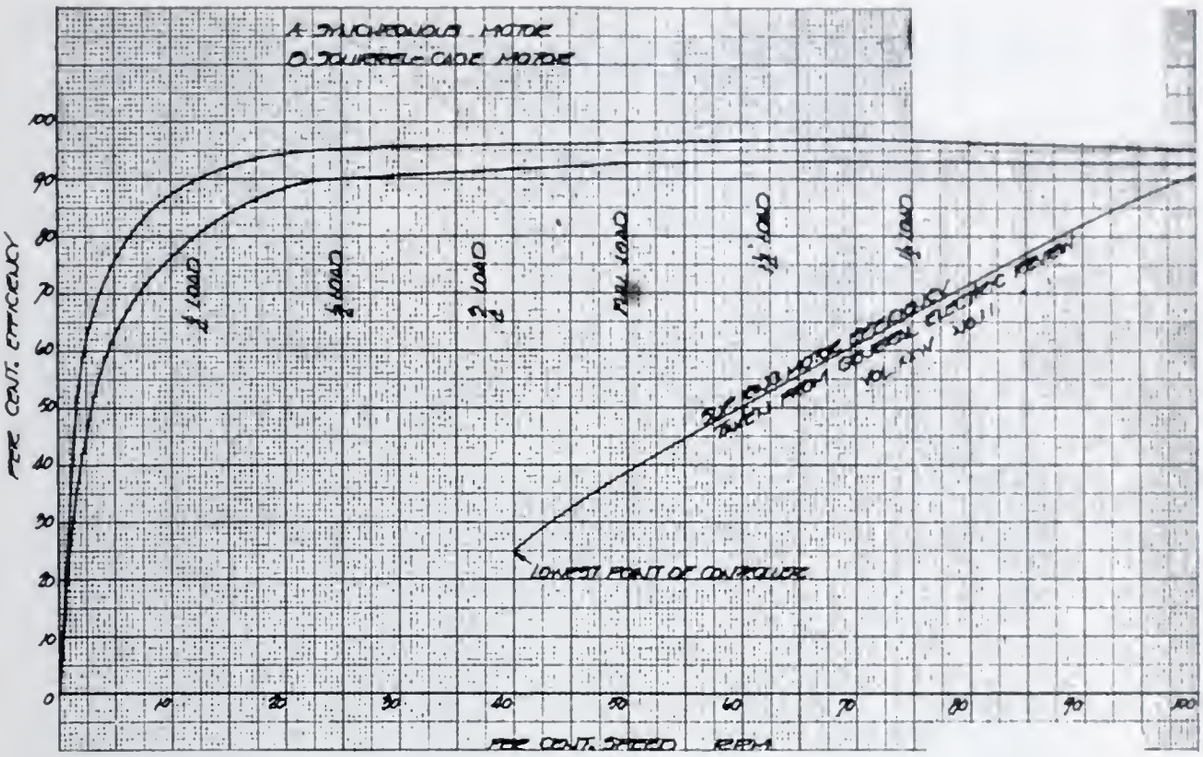

Fig. 6. Efficiencies of Constant-Speed and Slip-Ring Motors.

Fig. 7 was prepared for a large public-utility company, to compare the motor input of a slip-ring motor, two constant-speed, squirrel-cage motors using the movable vanes, and the same constant-speed motors with ordinary dampers. The shaded areas indicate savings with vane control.

In the majority of cases, the volume of gas to be handled by the fan at normal load is such that if any fan were employed using a slip-ring motor, the speed at this load would be from 70 to 80 per cent. of the full-load speed. For this reason, in order to show the highest saving with vane control over slip-ring motor control, it is advisable to use constant-speed, squirrel-cage motors, one on each end of the fan shaft.

A squirrel-cage motor may be purchased with two windings which will give full speed and half speed but at full load the lower speed will usually give a volume less than normal load requirements. For example, referring to Fig. 7, it may be seen that if the speed had not been changed at that definite point, curve B at the upper speed would have crossed over curve A and then the slip-ring motor would have shown less motor input than the constant-speed motor. Curve A shows the horse-power motor input for various volumes when using a slip-ring motor, while B, at two different speeds, shows the motor

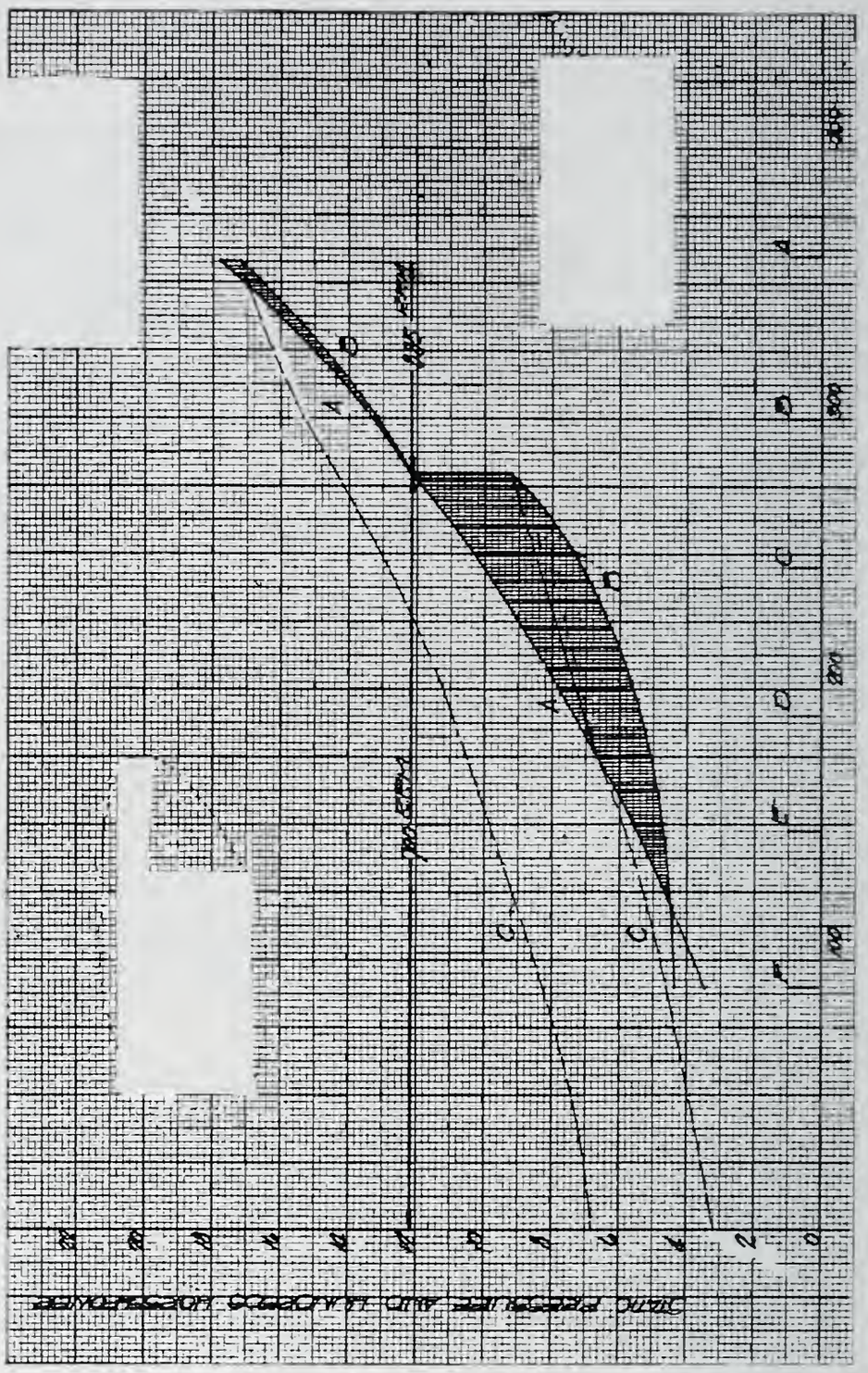

Fig. 7. Comparison of Motor Input.

input with a squirrel-cage motor. The shaded areas show the saving in horse-power effected by the squirrel-cage motors. This method of volume control thus makes possible the use of inexpensive, less complicated squirrel-cage motors and in this manner effects not only a saving in initial investment but a subsequent daily saving in power consumption.

Curve C, represented by the dotted line, shows the motor input if a squirrel-cage motor is used but with the volume controlled by an

ordinary boiler damper, the vanes in the fan inlets being in a fixed position. Naturally the motor input with this method is greater than with the other two but, nevertheless, there will be an appreciable saving over any other type of fan operated in a similar manner. This is due to the fact that with the new "Turbovane I. D." fan no allowance need be made for inlet loss. This fan can always be designed to deliver the maximum volume and pressure desired, and still give the greatest horse-power saving in the normal load range where it will be most used.

There is yet another point in favor of the two-motor arrangement. The old adage warns against carrying all the eggs in one basket. In like manner, carrying all the load on one motor offers only one-half the security against shut-downs. If the smaller motor goes out of commission, the larger one—while not as economical as the smaller when operating over the normal range—will carry the load just as steadily from maximum to minimum. If the larger motor gives out, the smaller, of course, can not reach maximum volume but it can carry 79 per cent. of the maximum, and certainly this is better than shutting down entirely.

With a slip-ring motor the spiral inlet vanes are stationary while with a single-speed, or with two constant-speed squirrel-cage motors, if the movable vanes are used instead of an ordinary damper, the vanes are opened and closed by a link-motion actuated by a worm-gear as shown in Fig. 8. Since the torque is slight, being approximately 350 to 500 foot-pounds, the worm shaft may be turned by hand or by a small fractional horse-power motor. The most recent arrangement is to connect this motor to whatever system of automatic combustion control is installed at the plant. The vanes are then opened and closed in exactly the same manner as the ordinary boiler damper. These inlet vanes overlap sufficiently to allow them to be closed tightly, if necessary. This eliminates the need of any extra damper, except in certain by-pass ducts. The ordinary boiler damper need not be installed, or, if it already has been in service before the "Turbovane I. D." fan is placed in operation, this damper should be fastened in a wide-open position when the inlet vanes are functioning.

An additional noteworthy feature is found in the fan impeller, which has curved floats, radial at the tip. This type is practically self cleaning, thereby avoiding the vibration and the loss of efficiency

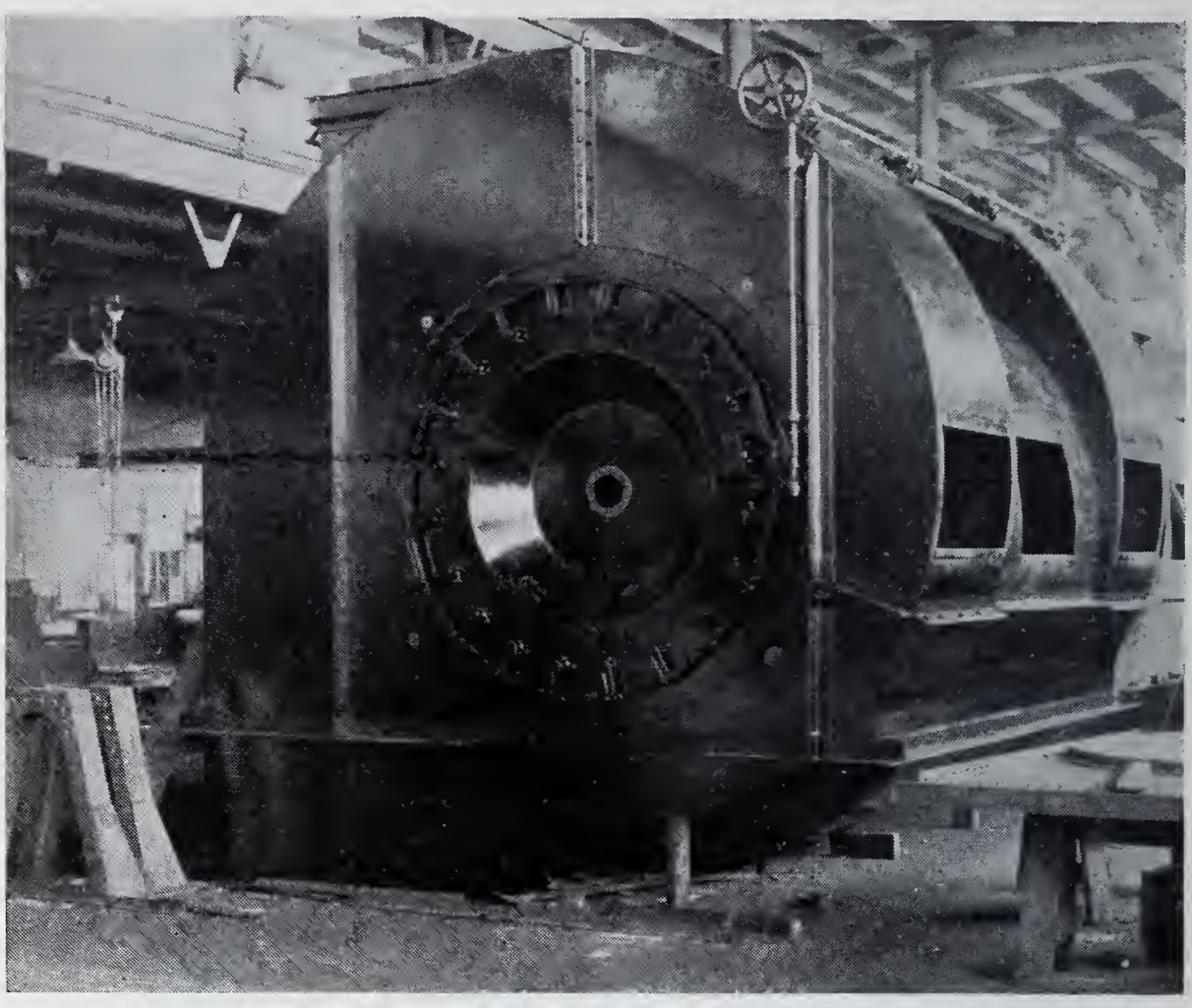

Fig. 8. Vanes Operated by Link-Motion.

caused by an accumulation of dirt on the wheel. The impeller is narrow and rugged, suitable for the high tip speeds demanded by the increased draft requirements of modern high ratings, particularly where economizers or air heaters are installed. This impeller is shown in Fig. 9. The alloy steel used in its construction permits an impeller

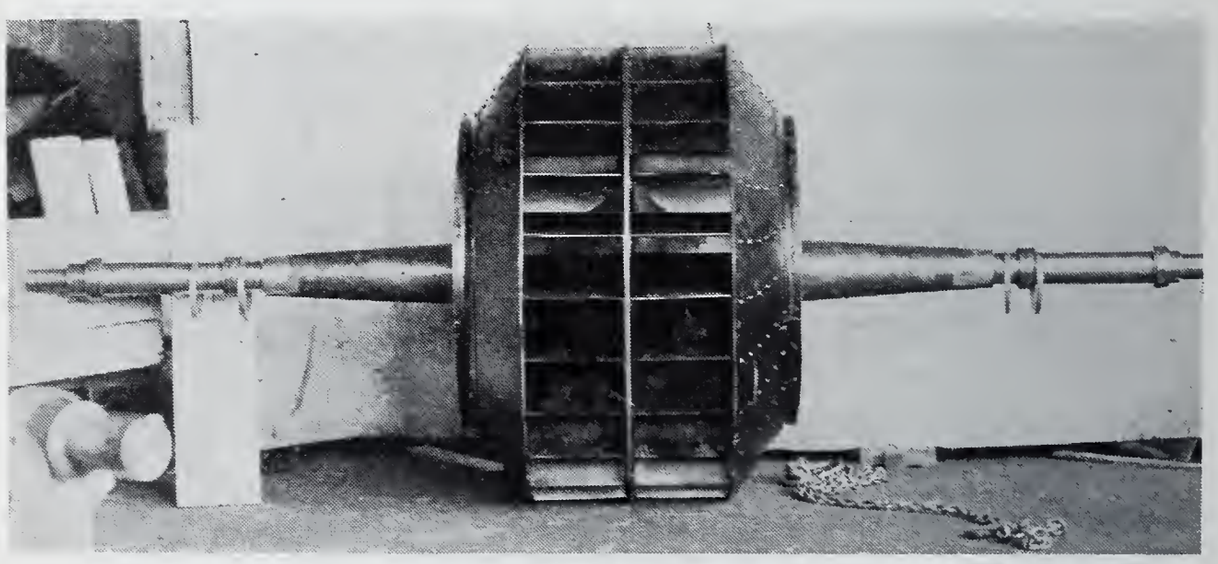

Fig. 9. Fan Impeller.

of this type to stand tip speeds of 25,000 feet a minute. All impellers, even for large volumes and high pressures, are of single wheel construction. No welding of any part of the rotor is permitted. After heat treatment, the resultant elastic limit exceeds 80,000 pounds to the square inch. The curves in Fig. 10, taken from authoritative

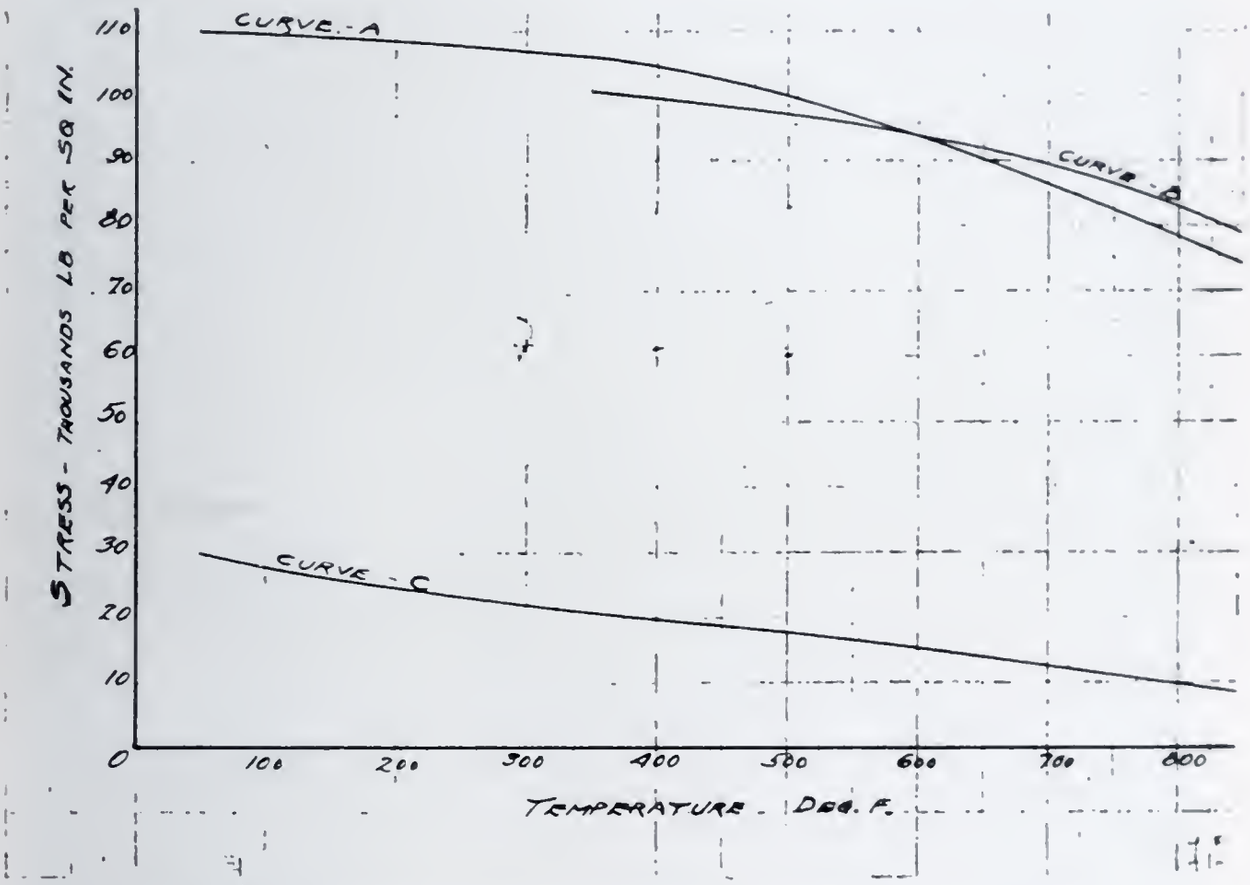

Fig. 10. Effect of High Temperatures on Elastic Limit of Steel.

sources, show a striking comparison between the elastic limits of mild steel ordinarily used in fan construction and special alloy steel similar to that used in the rotor of the "Turbovane I. D." fan. Curve A, for 1.02 per cent. carbon steel, was determined by T. M. Jasper, University of Illinois. Curve B, for "Hy-ten B" No. 3 alloy steel, was determined by V. T. Malcolm, Chapman Valve Company. Curve C, for mild steel containing 0.18 per cent. carbon, was determined by H. J. French and W. A. Tucker, United States Bureau of Standards. Comparing curve B for alloy steel with curve C for mild steel, it may be noted that even at a temperature of 850 degrees F. the elastic limit of the alloy steel exceeds 80,000 pounds to the square inch, whereas the ordinary steel has dropped below 10,000 pounds.

Thus far, due to the uniform gas distribution, we have not had any erosion trouble with this impeller, but in the event that such trouble should occur we are prepared to meet it with a steel-plate type of impeller, the floats of which can be easily removed and replaced. This impeller will fit into the same housing and run at the same speed but will require about 15 per cent. more power to drive it. Even though requiring more power we believe this arrangement will be less expensive than "stelliting." If the blades erode, do not try to retard this action with expensive alloys but have blades that can be easily replaced by cheap boiler plate.

Using such an impeller in the "Turbovane I. D." housing still gives us the advantage of tested inlet boxes plus the more economical method of volume control.

Since this fan has proved so successful for induced draft, it was found equally applicable to forced draft. Since inlet boxes are not ordinarily used with forced draft, our Research Department worked out a scheme of applying movable inlet vanes to the regular cone inlets by placing them radially in the form of V-shaped shutters, directly in front of the cones.

This method of vane control is also successful when applied to the fans ordinarily used for forced draft, particularly those with backwardly curved blades such as our "Turbovane" and "Silentvane" fans. In Fig. 11 these vanes, in a wide open position, are shown on a large "Turbovane" fan. Fig. 12 shows the method of moving the vanes.

Mechanical features are of primary importance, as the first duty of a mechanical draft fan is to operate without interruption, but, after mechanical excellence has been considered, power consumption becomes the most important matter.

Economically, fan horse-power must be considered in two ways. First is the station cost, from $75 to $125 per kilowatt capacity. The kilowatt requirement of the fan motor for maximum capacity reduces the available station capacity by just that amount, and the proportion of the total plant cost chargeable to the fan is the same as the proportion of the maximum fan-power requirement to the station capacity. Whether this charge is based on the original cost of the plant or on the plant value after 10 years is a matter of individual judgment.

Fig. 11. Vanes in Open Position.

The second consideration is the actual cost of the power taken by the fan. For this calculation there should be an average daily load curve of the plant. From this curve it is possible to make a table of concentrated values showing hours at enough different kilowatt outputs to represent the load curve fairly well. The kilowatt outputs are readily converted into fan volumes the values of which may be placed in the tables also. From the curve sheet furnished by the fan engineer, based on your system characteristic, the corresponding fan horse-power may be readily tabulated. From the motor information, the power consumption for each item in the table is now obtainable.

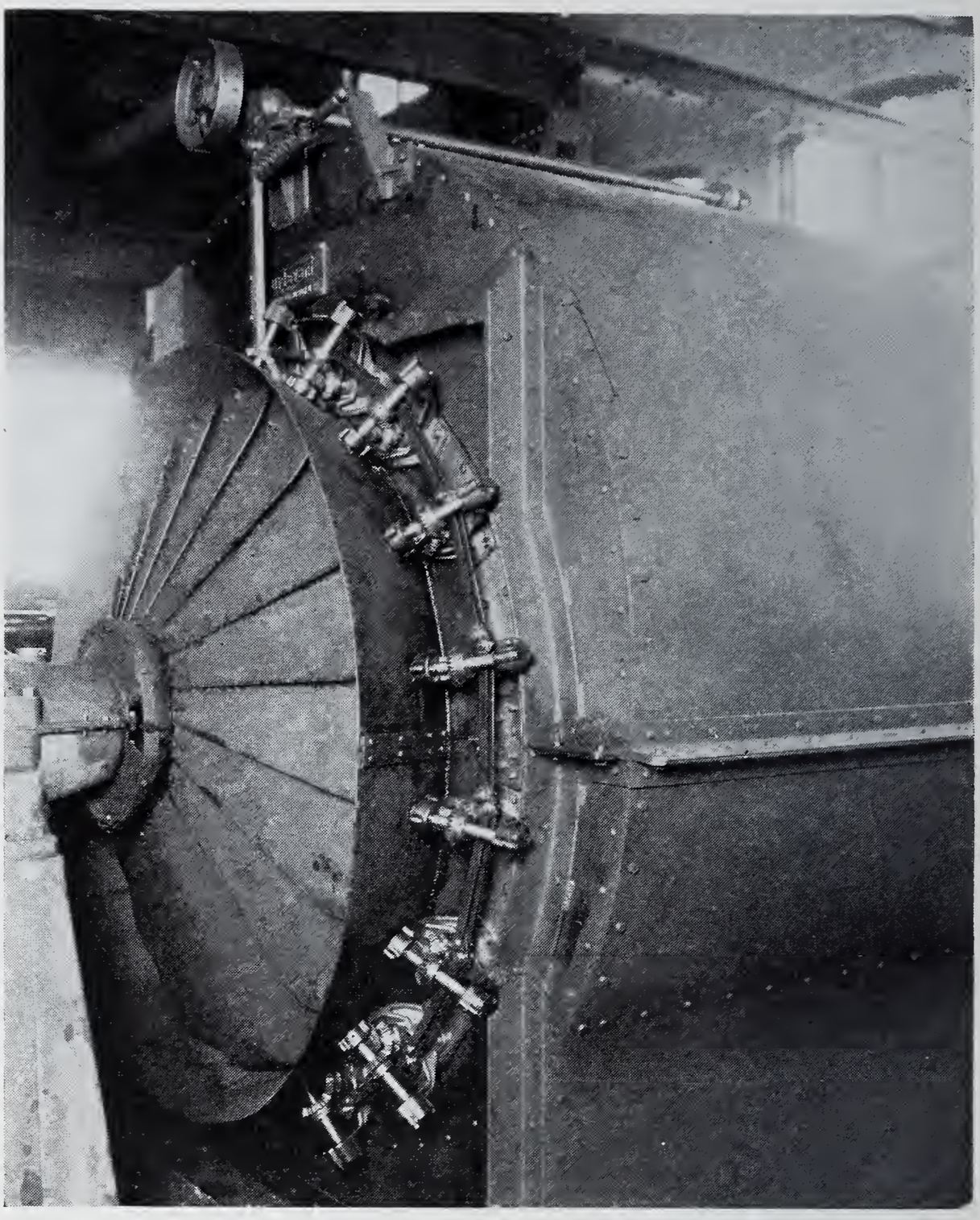

Fig. 12. Mechanism for Moving Vanes.

The final column in the table is for input horse-power or kilowatt-hours which may be summed up and multiplied by the expected power cost. It should then be capitalized at some proper figure. The economic cost of the fan could then be made up of three amounts:

1. Fan cost.
2. Capacity charge.
3. Capitalized power cost.

Whether all these steps are necessary in every case, must be determined by individual requirements.

When bids are received in response to specifications, the first impression is one of amazement at the wide range of prices, the variation frequently being as much as 300 per cent. The apparent discrepancy is greatly reduced if we first take out the bids on fans with forwardly curved blades. Any manufacturer who bids on this small, light type will have a low price. Of the other fans, a reason for the difference can be explained and, as a generality (to which there are, of course, exceptions) it will be found that the manufacturer with the highest prices offers the most for the money. Perhaps you want what he offers or perhaps you may decide that his equipment is unnecessarily rugged and the extra expense is not warranted. Such a decision arrived at with complete understanding is a proper function of the purchasing engineer. The decision that considers two proposals identical when they are not, is the one to be avoided.

There are two schools in fan design. One idea is to build as lightly as possible, taking a few failures but keeping the selling price down. The other is to build heavy enough to insure against mechanical failure, then go out and sell it. Of course, every manufacturer must make a profit or quit. The low price has a tremendous appeal. From the standpoint of profit it is an unsettled question which of these schools is the better. It must be realized that the most expensive parts of a fan are the impeller, the bearings, and the shaft. The cheapest parts are the cast-iron pedestals and the housing. When only a total weight is considered, a hidden error may be introduced by crediting weight that one manufacturer has put into a casting costing four cents a pound, against weight which another maker has designed into an impeller at 50 cents a pound. The decision can legitimately be made as to whether the extra gages in the impeller are worth paying for, but we must at least know that they are actually present in that fan and not in the other. The proper gages to use in a fan impeller are not determinable by calculation alone. The light-gage wheels figure strong enough but we have learned of failures in certain competitive makes which indicated vibration fatigue. The only way to determine proper gages in fans is by experience.

There is another important point which the buyer must watch.

The high pressures and tip speeds of to-day are requiring, more and more, the use of alloy steels. The proper use of alloy steel requires heat-treating furnaces, pyrometric control, hardness determination, and experience. We have known of recent cases where alloy steel was actually built into the fan but handled just like mild steel, with the result that it was delivered at the customer's plant almost as hard as glass and almost as brittle. Naturally a serious failure occurred. Where alloy steel is to be used it is advisable to find out exactly the treatment it is to receive. If your request for the method of treatment is ignored or answered vaguely, it is a sure indication of the need for special caution in dealing with that manufacturer. The manufacturer should state his heat treatment specifically, together with the composition of the steel. All alloy steel should be tested for hardness after treatment. The test is a simple one and is the most practical check on the reliability of the final product. Unless you can get a definite statement, buy elsewhere and let some other unfortunate help that concern to get its experience.

In order to secure bids that can be readily and correctly analyzed, the following suggestions may prove helpful.

Where fans are to be used with inlet boxes, these boxes should be bought as part of the fan and all guarantees based on a tested performance with the inlet boxes in place. Performance curves should be required plotted with volumes as abscissæ, and with horse-power, static pressures and static efficiencies as ordinates. On the curve sheet should be given the dimensions and areas of the fan inlet and outlet when ducts are to be connected thereto. Where two fans are substantially equivalent in apparent performance, one may require a duct area (either outlet or inlet) larger than you had contemplated using; and as the areas of the ducts, to avoid change in fan performance, must be not less than the fan areas, the larger duct might prove the chief factor in reaching an adverse decision.

In his specification, the purchaser should give sufficient figures of volume with the corresponding pressures expected, and, if induced draft, the temperatures, to cover the full range of operation. It would help the bidder if, in addition to this tabulated data, the values were plotted on a curve sheet and the curve labeled "system resistance." An additional curve sheet could then be required from the bidder plotted with volumes as abscissæ and fan horse-powers and

speeds as ordinates, calculated to correspond at every volume, to the pressure requirements of the system characteristic. The fan horsepowers should be converted into motor input, making due allowance for speeds. You then have full performance data in such shape that you can readily decide whether to use, for example, our vane control with constant-speed motors, or variable-speed drive with our fan or some other.

Since the type of motor and the speed are such important items in determining the price of the motor, purchasers of motor-driven fans are urged to reach a decision as to the make of fans which they will buy, only after careful consideration has been given to the combined cost of the fans and motors, and not the fans alone.

Where it has been previously decided to operate the fans with constant-speed, squirrel-cage motors, regardless of the make selected, it is advisable to capitalize the motor input saving of one make of fan over another. From 0.5 to 0.6 cent per kilowatt-hour is a fair average power charge.

DISCUSSION

C. A. Carpenter:* I would like to express the appreciation of the members of this Society to Mr. Darnell for coming here on short notice. The information he has given us is valuable and the points he has brought out are well taken. I am not familiar with this new inlet vane fan.

In connection with waste-heat fans, the relative velocities through the wheel and casing are frequently overlooked. Mr. Darnell pointed out the fact that the typical forward curve fan has high velocities. When purchasing waste-heat fans, the velocities through the wheel and casing should be kept down to the lowest economical point. I believe Mr. Darnell will agree with me that r.p.m. alone should not be greatly stressed. It requires certain velocities to set up pressures with any particular fan design. As far as relative velocities are concerned, it makes no difference whether a five-foot wheel runs at 1000 r.p.m. or a 10-foot wheel runs at 500 r.p.m.; the speed of the air through the wheel and casing would be the same if the design were kept constant. The important consideration is to select a fan with relatively low volumetric efficiency so that the volume of gases passing through the wheel per revolution is kept down.

*Carpenter & Byrne, Pittsburgh.

J. R. DARNELL: That is true to a certain extent; but heretofore they have been asking for such large fans in proportion to the volume that it has run the cost up quite a bit and we believe from our experience in powdered coal that we should be able to build smaller fans which are not of the steel-plate type and still not have serious erosion troubles because of relatively large inlet and outlet in comparison to the size of the wheel. Also, due to the fact that the gas is evenly distributed to all parts of the wheel, whatever erosion there may be at any one point will be very small.

As I showed you, powdered coal is practically as erosive as cement dust, so that the design which will work satisfactorily with powdered coal ought to work all right with cement. Of course temperature may have some effect on erosion. You take a certain piece of steel at 500 degrees and pass a certain amount of erosive material over it, and do the same at 1000 degrees and there may be some difference in the erosive effect—that we do not know.

C. A. CARPENTER: As I understand it you stated that you can place a paddle-wheel in the same casing, operating at the same speed as the new wheel design. The variation in wheel diameter would be slight, if any. Does it not follow that your new fan has a relatively low volumetric efficiency? Volumetric efficiency and peripheral velocity for a given condition must be fixed if substitution of one wheel for another is possible. Paddle-wheel fans have low volumetric efficiency.

J. R. DARNELL: Yes, as I stated, the general characteristics of this new fan are practically the same as the paddle-wheel fan except that due to the forward spin of the gas we get a higher efficiency than we would with the ordinary paddle-wheel. With the spiral inlet box, we get 65 to 67 per cent. static efficiency, whereas the old paddle-wheel fans show about 60 to 62 per cent. static efficiency, based on open inlets. When you put on an inlet box, your efficiency will drop 10 or 15 per cent., perhaps more.

A. GRODNER:* Aside from the effects of abrasive dusts on induced-draft fans, I would like to know also the possibilities of employing such fans for gases at high temperatures. At the present stage of development of recuperators, and especially of the regener-

*Blaw-Knox Co., Blawnox, Pa.

ative types of air preheaters, the problem is not in the ability of the recuperative or regenerative materials to resist the high temperatures encountered, but rather in the ability of the induced-draft fans to cope with the higher temperatures of the exhaust gases. Such gases have at times, at their exit from the air preheater, temperatures of between 800 and 900 degrees F. I would like to know, therefore, what the limiting temperatures for induced-draft fan gases should be.

J. R. DARNELL: There are a good many factors entering into it so that you can not make any hard and fast statement. Along with temperature that may be encountered there is this volume and pressure that the fan must maintain, and the pressure is determined by the type, speed, and head. Even with low temperatures and using alloy steel, we must make the blades strong enough to stand up by making them narrower than standard design. As the temperature goes up, this factor of safety must be more and more emphasized. Even with alloy steel, the elastic limit is much lower as the temperature goes up. We have fans that have been operating in an oil refinery at pretty high peripheral speed, at about 1100 degrees F. Of course, there is very special alloy steel construction in the rotor, and the bearings and the shaft are water cooled.

There are a good many different alloy steels. Where we have very high temperatures we have used "Atha" steel which has worked out very satisfactorily. It all depends on the operating conditions such as the peripheral speed that must be maintained, the type of fan, the temperatures encountered, and whether the gas is clean or contains abrasive or corrosive material. We do not worry particularly about temperatures up to 1100 degrees but have never tried anything much above that. In oil refineries the gas often runs between 1100 and 1200 degrees. Where they have such high temperatures they do not try to put the gas directly into the fan. In oil refineries fans are used for recirculation of flue-gas to reduce the temperature in the furnace. In most power-plants, economizers or air heaters are used to reduce the temperature entering the fan but sometimes it is 750 to 800 degrees where the boiler rating runs up to 500 or 600 per cent.

F. FALLA:* Can you tell us about the use of roller-bearings on fans?

*Engineer, Edge Moor Iron Co., New York.

J. R. Darnell: I am glad you brought that up. I don't think any fan manufacturer knows as much about roller-bearings as he does about sleeve bearings. In some cases, they work very nicely but we have one case just now where it has been very difficult to balance the fan, particularly since the roller-bearing had only one race. Where they have two races and where you can get considerable bearing surface, it is not so hard to balance the fan. We are now considering the possibility of putting two bearings on each end of the shaft to get a balance with this particular type of roller-bearing. With other types of roller-bearings, we do not have any trouble at all in balancing but where there is a high temperature there is always the question of keeping these bearings cool. Manufacturers of roller-bearings differ as to the temperatures and operating conditions, and we have not been able to get any real decisions as to what they will do. One manufacturer told us that if the temperature went over 300 degrees he wouldn't guarantee his roller-bearing. Another one told us he would go up to 500 degrees. With either of those comparatively high temperatures, unless you have some special design to keep the grease from melting and running out, you will be up against it. For induced-draft fans, particularly, we will not use roller-bearings unless the customer will assume the responsibility. In forced-draft practice, however, we have a number of fans, particularly in heating and ventilating work, operating with roller-bearings and they operate very satisfactorily.

I do not say this to detract from roller-bearings for our present knowledge is limited but thus far we are not trying to push roller-bearings for induced-draft fans unless the customer asks for them and will assume all responsibility.

C. A. Carpenter: I can confirm the last comment. Recently the same experience occurred when a customer desired to try out anti-friction bearings at high temperature. We were unable to locate any bearing company willing to make definite guarantees, and consequently we recommended water-cooled sleeve bearings.

One other point might be discussed. There may be some present who have not had experience in converting the pressure-making ability of fans for changes in temperature. The objection to high rim speed comes up. With temperatures around 1000 to 1100 degrees, if draft

loss is appreciable, rim speeds must be high. Men in the fan business would like to stress this fact so that buyers will realize that when they ask for high draft at high temperature they require a machine to stand excessive tip speeds.

J. R. DARNELL: I am not certain what point you wish illustrated but perhaps the following will serve. Suppose that a customer wishes a fan to deliver 200,000 cubic feet per minute of gas at 900 degrees and 12 inches static pressure. To determine the speed at which the fan must run we must first calculate the "cold static pressure"; that is, what pressure would have to be maintained if the fan were to operate at the standard temperature of 65 degrees since all our charts and curves of fan characteristics are based on air at that temperature. The hot static pressure is converted into cold static by two factors, the first being the ratio of absolute temperatures and the second the ratio of densities of gas and air. At 900 degrees the absolute temperature is 1360 degrees, and at 65 degrees it is 525 degrees. The ratio of absolute temperatures, therefore, is 2.59 to 1. At 65 degrees the weight of one cubic foot of air is 0.075 pound, and the weight of one cubic foot of flue-gas usually is considered as 0.078 pound for coal firing (oil and gas firing are exceptions). The ratio of these densities is $0.075 \div 0.078$ or 0.96. Multiplying our hot static pressure by these factors of 2.59 and 0.96 we get 29.8 inches cold static pressure which the fan must produce. This is assuming operation at or near sea-level. If the elevation is less than 1000 feet we usually do not make any correction for this condition but at higher elevations this point must also be considered. Suppose the fan were to operate at 5000 feet above sea-level where the normal barometer is 24.8 inches when 30.0 inches is standard at sea-level. Here we must multiply our 12 inches hot static pressure by a third factor which is the ratio of $30.0 \div 24.8$ or 1.21. This will give us a cold static pressure of 36 inches instead of 29.8.

To produce such high pressure the peripheral speed of the fan must be in the neighborhood of 22,000 feet per minute depending on the type of fan selected. It can be readily seen, therefore, that the higher the temperature the greater must be the peripheral speed to produce the same results.

PRECAST CONCRETE PILES AND SPECIAL EQUIPMENT FOR THEIR HANDLING AND PLACING*

By Maxwell M. Upson†

All engineers who have to do with foundation problems know something of precast concrete piles. Their increasing use demonstrates that as construction units they have a real place in the engineering world. It is the purpose of this paper to discuss some of the structural and economic factors that contribute to this increasing popularity.

In approaching the design of a foundation, the analytical engineer first asks, "How can I provide an adequate foundation at a minimum cost per ton of superimposed load?" The term "superimposed load" is used advisedly, since this load is frequently quite different from the load at the base of the foundation footing.

The honest answering of this question is responsible largely for the wide use of the Raymond cast-in-place pile. Because of its taper, and the driving of a steel core which withstands excessive abuse and requires a minimum amount of cushioning, and because the shell holds the compression of the ground attained in the driving, exceedingly high frictions are obtained per square foot of surface area. This means that the safe load on this type of pile is very great per linear foot of piling. In other words, heavy loads are carried on short piles; which, in turn, means more tons per foot of piling. Reference will be made later to the relation of this skin friction to that of the precast pile.

It is well known that the Raymond pile has its limitations, and our attention will now be directed to the matter of substituting the reinforced concrete pile.

In giving consideration to the use of any article, or the adoption of any policy, it is logical and proper that the advantages and disadvantages be carefully catalogued, so that they may be weighed one

*Presented January 8, 1929. Received for publication April 2, 1929.
†Vice-President and General Manager, Raymond Concrete Pile Co., New York.

against the other. With this in view the following characteristics of reinforced concrete piles are set forth:

1. They can be made in long sections, far exceeding the practical length of the cast-in-place type of pile. In practice they are sometimes used up to a length of 125 to 140 feet.

2. They have great value as columns, and are particularly adapted to the support of a load where water, silt, or other non-supporting material can penetrate.

3. Because the concrete is cured and seasoned prior to placing the pile, it is capable of resisting the action between high and low water, of salt water, or other exposures.

4. In soils of low frictional value it is possible to design a pile of large surface area so that sufficient resistance may be developed to permit a heavy loading per unit.

5. The precast pile with its upper end extending up to any elevation desired, provides the connection between the embedded pile and the superstructure, thereby frequently eliminating the cost of the footings, the coffer-dams, and columns above the footings.

Against these advantages must be weighed the following handicaps which are inherent in this type of pile construction:

1. The time required for curing (usually 30 days, unless early-strength cement is used).

2. The space necessary for the casting. This is a serious matter in thickly populated centers, since an area of considerable magnitude is usually required in order to lay out an economical casting yard.

3. The excessive mass in long piles, which makes the driving difficult and penetration somewhat uncertain.

4. The impossibility of hard driving, because of the cushioning necessary to avoid destroying the tops of the piles.

5. The impossibility of predetermining the exact length of the piles causes great uncertainty as to the ultimate cost, since splicing or cutting off involves serious expenditure.

6. Notwithstanding the possible increased loading per pile, the cost per ton of load carried is usually somewhat greater than that of the cast-in-place pile.

Regardless of these handicaps, Mr. Precast Pile is stepping forward with increasing confidence to take his full responsibility in the foundation world.

Perhaps no better presentation of this subject can be made than by setting forth in full the conditions and tests of the ground underlying the Pontchartrain bridge, where some 4000 precast concrete piles were used.

Fig. 1 records most of the essential information on the test of an 81-foot wooden pile with seven-inch point and 15-inch butt. It

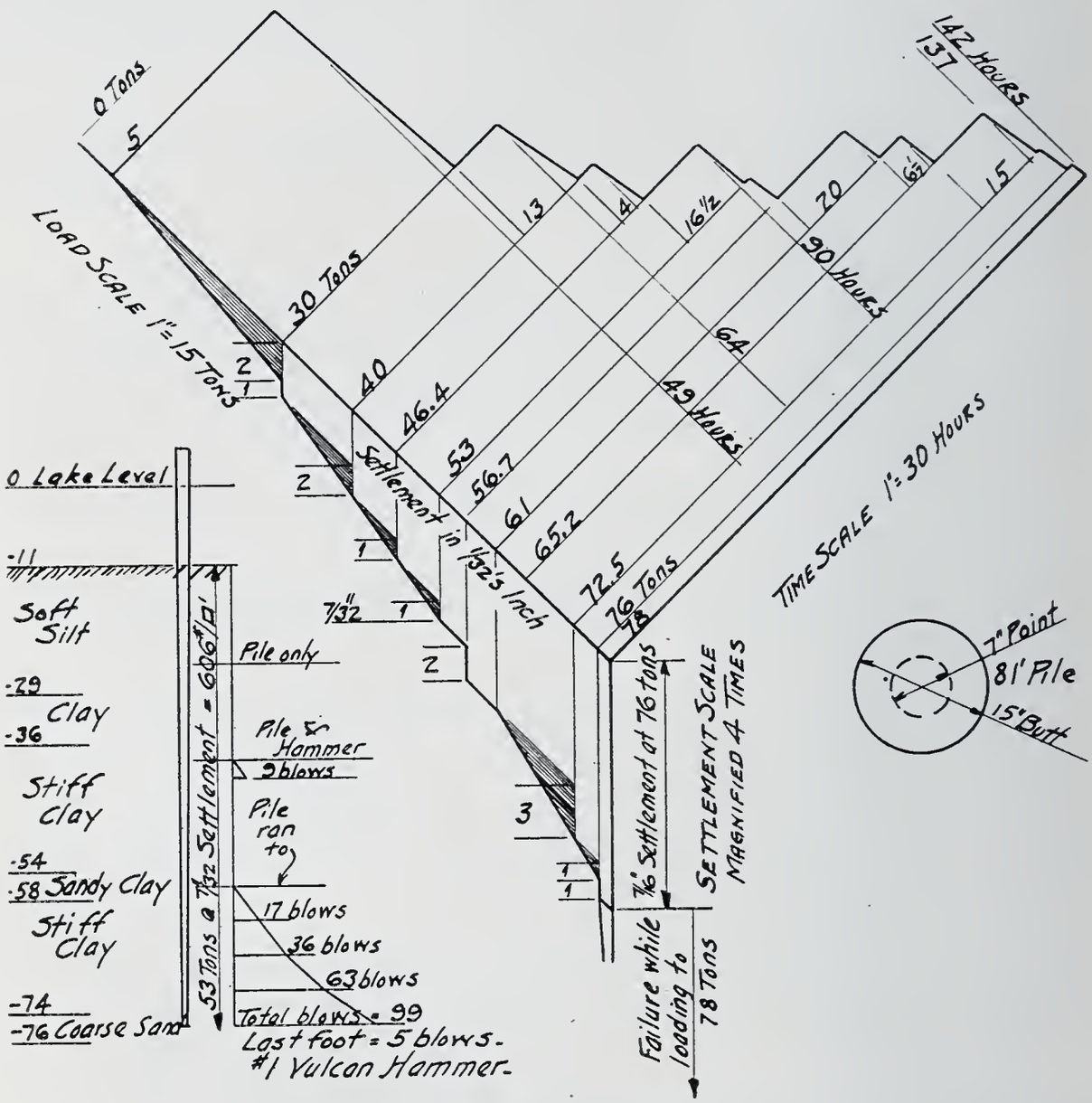

Fig. 1. Test of Wooden Pile.

will be observed that this pile penetrated 38½ feet below the surface of the lake under the weight of the pile and hammer, and was driven for nine blows, and then ran 15 feet to minus 56 before actual driving

began. It then required 96 blows to drive the pile the remaining 20 feet; that is, to minus 76. Under a test load, this pile began to show slight settlement at 30 tons, and approximately ¼-inch settlement at 53 tons. The friction broke completely at 78 tons. This pile was driven on March 11, and tested on March 15, 1926.

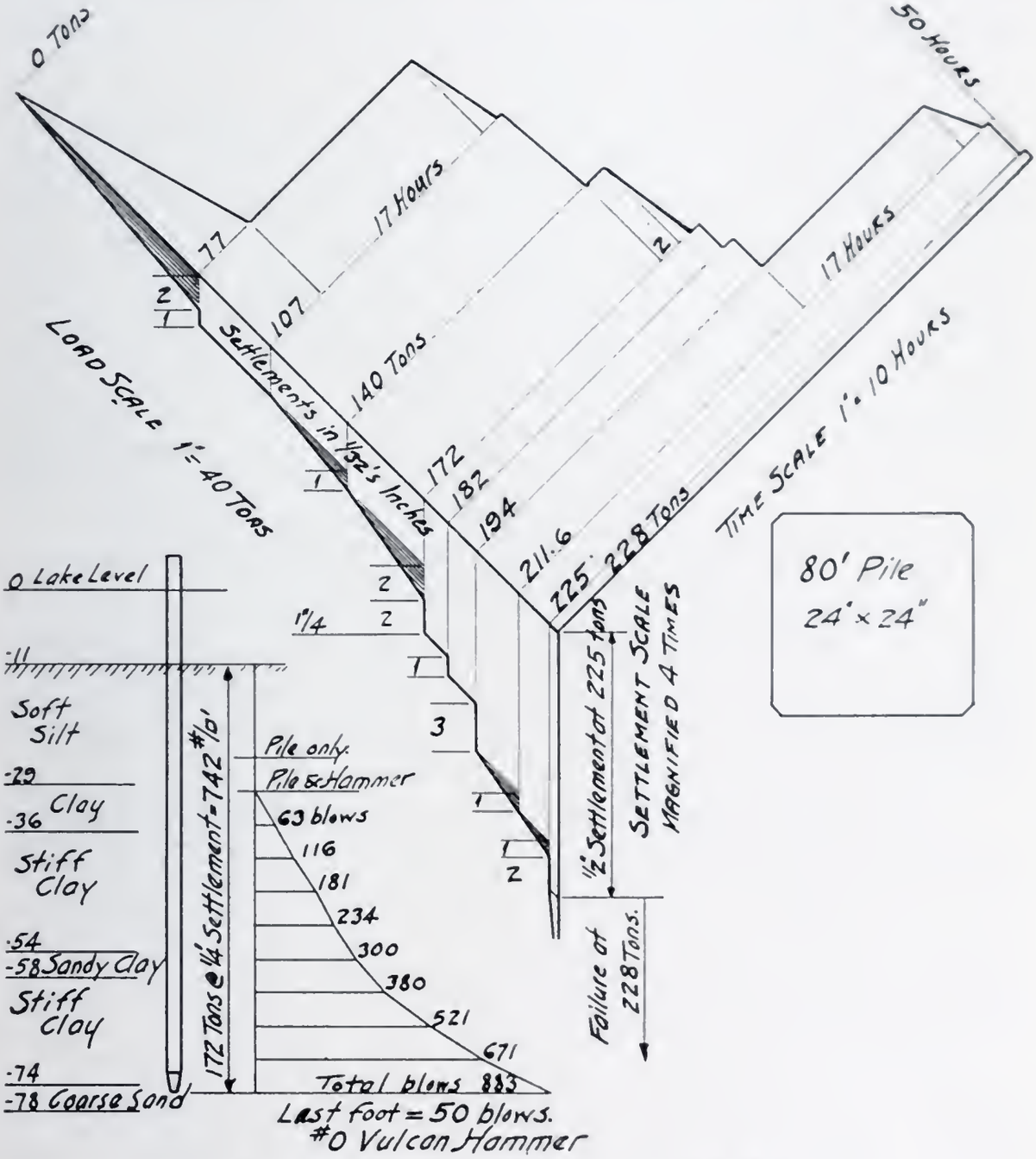

Fig. 2. Test of Reinforced Concrete Pile.

In this same ground was driven an 80-foot reinforced concrete pile, 24 by 24 inches in cross-section, illustrated in Fig. 2. It will be observed that this pile penetrated to minus 30 under the weight of the pile and hammer, and was driven to grade minus 75

feet with a total of 883 blows. A slight settlement was evidenced at 77 tons, and ¼ inch at 172 tons, and a complete slippage at 228 tons. This pile was driven October 9, and tested October 22-24, 1926.

From these tests the engineers decided that the safe load for the wooden pile would be about 12½ tons, while the safe load for the concrete pile was placed at 50 tons. Without taking other factors into consideration this would indicate that one concrete pile would do the work of four wooden piles.

At this point, we must consider other factors that are important in determining the total cost of the structure. The foundation provides support for a reinforced concrete trestle bridge. The load must be carried from the bottom of the lake to the superstructure. It is here that the concrete pile provides a column direct to the capping, thereby eliminating the expensive footings, coffer-dams and columns, all of which would have been necessary had wooden piles been used. Comparing the total cost of the wooden pile substructure with the reinforced concrete pile, a material saving is shown in the use of the latter. Here we find conditions under which practically all of the advantages of the precast type of pile are applicable.

On the assumption that these are both friction piles—which is approximately true since strata of hard material are very thin and easily penetrated—the unit square-foot friction of the wooden pile is 606 pounds as against the unit square-foot friction of 742 pounds on the concrete pile, at a settlement of ¼ inch.

It would be assumed—although it is almost impossible to produce confirmatory evidence—that, if a uniform material is penetrated, the large displacement of the concrete pile with its large cross-section would tend to increase the compression of the ground and, in consequence, the unit friction, as compared with the wooden pile, the size of which is limited because of the normal growth of timber.

Such should be the facts if the excess weight of the concrete pile itself is to be compensated. The relationship of the friction shown in these two tests—that is, 606 to 742, in which the weights of both piles have been taken into consideration—would indicate that such a compensation really existed. However, other tests in this same series do not demonstrate this fact, all of which indicates that the effect of the carrying power of the point of the pile materially affects the value of the unit surface friction.

Referring again to the comparison between the friction per surface foot of the Raymond type of pile (which is driven with a steel mandrel capable of withstanding severe punishment under the hammer, and with a shell to hold the compression of the soil which has been attained by driving) it is quite usual to develop skin frictions of from 1200 to 2000 pounds per square foot under the same ¼-inch settlement. In many cases, this occurs where the point of the pile is in soil that is much softer than the soil at the top of the pile.

The design of the reinforced concrete pile is comparatively simple, but, unlike the design of most structural units, has to do not with the ultimate use to which the unit is to be subjected, but with the stresses to which the unit is subjected during the period that it is curing and being placed. The design, therefore, hinges upon the method of handling and the type of apparatus that is to be used in handling and placing. This involves not only the stresses due to handling the weight, but also the stresses to which the pile will be subjected in the driving.

Special reinforcement should be provided in the head of the pile, so that the concrete will not be damaged by the hammer. If the pile is long, the first determination to be made is at how many points will it be lifted. If it is suspended at two points, the design is comparatively simple; if at three, it becomes more involved, and at four and five even more so, particularly when the characteristics of the compensating devices which are used in the handling must also be taken into consideration. All such matters are comparatively simple, provided the apparatus is designed to work in harmony with the engineer who designs the structural members.

Another factor which may seriously affect the permanency of the piling, is the location of the steel in the pile. The Joint Committee on Reinforced Concrete provided that all steel for reinforcing of concrete subjected to the action of salt water must be placed three inches from the surface of the concrete. In cast-in-place structures this specification can be easily complied with; in precast units the adherence to this specification subjects the members to a very serious weakness.

It is apparent to engineers that in order to get the stress into a rod which is three inches from the surface, in a precast unit, the

concrete at the surface will in itself have to take considerable tension. This tension must of necessity form small cracks or openings, which open avenues of admission to water. It is, therefore, usually the best practice to keep the steel not more than two inches from the surface of such members. By so doing, and exercising great care in the proportioning of the concrete, it is possible, in the opinion of the writer, to provide a unit that will withstand all ordinary exposures to which piling of this kind is subjected.

In the event that the concrete is subjected to the action of moving ice, it is recommended that oak planks be strapped onto the piles at the ice zone, so that this abuse may be taken by a cheaply renewable member. In other respects, the experience of the company with which the writer is associated (which measures a period of 20 years) leads to the belief that precast piling of this character, properly designed and placed, forms a structure of great permanence and extremely low in cost of maintenance.

From the foregoing it is evident that the success of the design and construction of precast concrete piles hinges largely upon the methods and apparatus used. For that reason it may be of interest to include a few pictures which illustrate the methods and equipment which have been employed in building representative structures of the type under consideration. For this purpose I shall refer to three operations of considerable magnitude:

1. A bridge five miles long across Lake Pontchartrain. This involves some 2800 piles, 24 by 24 inches in cross-section, varying in length from 55 to 85 feet.

2. A bridge across the James River connecting Newport News with Portsmouth, Va. This really consists of three bridges, aggregating in all about five miles. The main span across the James River is a little less than four miles. Here some 2500 piles 18 by 18 inches and 24 by 24 inches in cross-section were used, their lengths varying from 40 to 115 feet.

3. A bridge across San Francisco Bay connecting Hayward on the east bank with San Mateo on the west bank. The bridge portion of this structure is a little more than seven miles long, and the approaches are a little less than five miles, making in all a structure approximately 12 miles in length. In this the 4854 piles varied in

cross-section from 16 by 16 inches to 24 by 24 inches, and in length from 40 to 105 feet. In general, the same methods and types of apparatus were used.

In all instances piles were manufactured in casting yards about 250 feet wide and between 1000 and 1500 feet long. These are illustrated in Fig. 3, which shows the lay-out of the San Mateo casting

Fig. 3. Casting Yard. Front View.

yard at Alameda, Cal. On the right is the pile casting yard with the bins for concrete aggregate, locomotive crane for feeding, and a traveling gantry in the background. On the left is shown the casting yard for the precast slabs and beams, which will be discussed later.

A view of this same yard taken in the opposite direction is shown in Fig. 4. Here the pile casting yard is shown on the left, and the slab and beam casting yard on the right. It will be observed that both of these yards extend out over the water, so that the gantry cranes can deliver their loads onto the scows.

Fig. 4. Casting Yard. Rear View.

The essential apparatus in the casting yard is the gantry crane, which is well illustrated in Fig. 5. This crane has a span of 127 feet,

Fig. 5. Gantry Crane in Casting Yard.

and in the picture is shown handling a pile 95 feet long and 24 by 24 inches in cross-section. This pile weighs 29 tons. The crane is used not only to handle the pile from the forms to the curing yard, and from the curing yard onto the scow which is placed between the gantry legs, but also to handle the reinforcing steel from the assembling yard to the pile forms. In the placing of 250 to 400 yards of concrete a day, naturally this machine has to move rapidly. For that reason it is designed and built for high speed and really carries a large tonnage during an eight-hour period.

The beam from which the pile is lifted with the compensating devices, is better shown in Fig. 6. Here in the foreground are seen

Fig. 6. Compensating Devices on Gantry Crane.

the reinforcing cages ready to be placed in the form. The piles in storage ready to be loaded out onto the scow (which is shown in the left background) are shown in Fig. 7.

Please observe that all the piles are carefully covered with burlap on which a sprinkler plays continuously. Proper curing is unquestionably the most important factor in securing dense and impermeable concrete. Reference will be made to this later.

Fig. 7. Precast Piles in Storage Yard.

The pile forms, which are usually supported on hand-driven stakes in order to insure against uneven settlement, are carefully alined and cleaned. They are greased prior to the placing of the reinforcement and later poured by means of buggies from the concreting plant, which is shown in the background. Corners of piles are rounded so that no sharp edges are presented for abrasion or spalling during handling. Fig. 8, a view of the Newport News casting plant, illustrates some of the methods.

Immediately following the casting, the green concrete is covered with bagging or other absorbent material which is kept saturated with water. Experience teaches that no part of the making of good concrete to withstand freezing and thawing, and the destructive action of salt water, is more important than proper curing. It is found that, unless the surfaces are kept saturated constantly for the first six or eight days after the concrete is poured, minute cracks develop which afford openings for the entrance of water. Concrete to be permanent must be so made that water will not penetrate it.

With the piles cast and placed on the scow, the next operation has to do with the driving. The handling and placing of ordinary

Fig. 8. Pile Forms in Casting Yard.

wooden piles or concrete piles in quiet water is quite different from the handling of extremely long and heavy piles in a sea that may run from three to five feet high. In structures of the character under consideration it is important that piling be placed accurately. The specifications in some instances required the piles to be within one or two inches of the exact location. For this purpose it is necessary to provide a driver of rather unique construction. It is shown in rear view in Fig. 9. Stripped of its details it is essentially a very large scow provided with four sets of leads, an A-frame derrick with 105-foot boom, and four timber spuds 24 inches square and 60 feet long. These spuds are equipped with a double-gear steam-engine, so that, after the driver has been pulled into its position by its anchor lines, the engines can exert about 15 tons downward thrust on each spud, thus steadying the scow and holding it in place. These spuds partly lift the driver out of the water and make it practically secure against the wave action and the swinging of the boom with its heavy load.

The four leads on this driver are mounted on a movable base, which is designed to roll crosswise and to slide fore and aft. The movements of these leads are accomplished by means of worm screws

Fig. 9. Derrick at Rear of Special Pile-Driver.

driven by three steam-engines of 10 horse-power each. By the use of this apparatus it is possible to locate accurately the center-line of all four leads, even though the driver scow when spudded up is some two or three feet out of position.

Driving is accomplished by picking up the four piles, constituting one bay, one after the other, placing them in the leads and letting them rest on the bottom. It will be observed in Fig. 10 that one of the leads from the main boom is fastened securely to the reinforcing steel, so that the pile is perfectly plumb when it is let down into the leads.

With the four piles placed in the leads, the two hammers are operated simultaneously, as shown in Fig. 11, driving the piles to their final penetration. At all times the position of the pile is checked so that the leads may be moved to bring the head of the pile to its proper place.

On Lake Pontchartrain and on San Francisco Bay, both of which are subject to trade-winds, and where the exposures are from 15 to 25 miles, heavy seas develop every day. At either of these locations it would have been impossible to work continuously with any ordinary floating equipment. For that reason the method just de-

Fig. 10. Under Surface, and Alinement of Piles.

Fig. 11. Longitudinal Batter Piles.

scribed was most efficacious in making rapid and economical progress. The alinement of piles after driving is illustrated in Fig. 12 and 13.

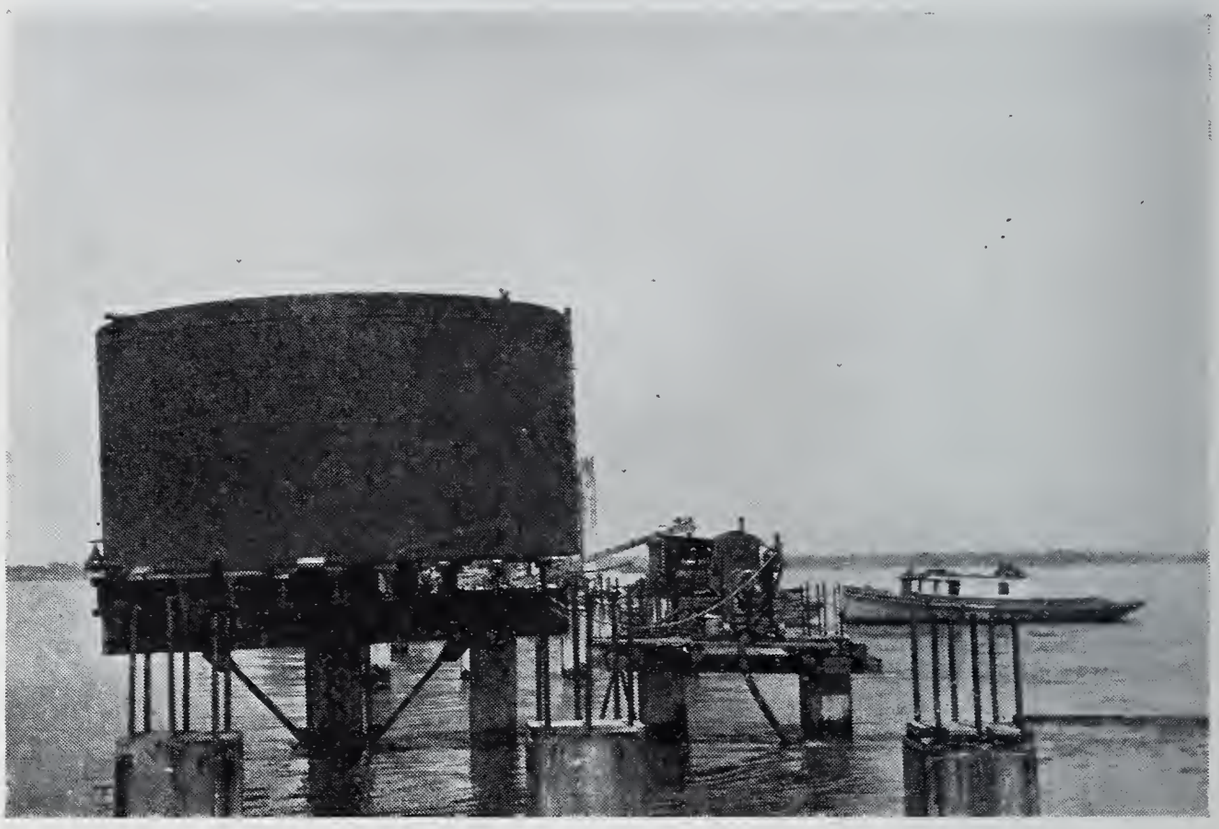

Fig. 12. Steel Water Tank Used in Testing Piles.

Fig. 13. Lowering Precast Slab Unit into Place for Bridge Floor.

Where batter piles are required, they are driven with either a derrick-scow with leads, or a very high single lead machine. Fig. 14

Fig. 14. Casting Yard for Slabs and Beams.

shows longitudinal batter piles on the San Mateo bridge, driven in 45 feet of water and penetrating to about minus 85. These piles hold 35-foot precast reinforced concrete spans.

It will be of interest to all construction engineers to state that on the San Mateo contract, 7600 linear feet of bridge were completed (that is, piles driven, slabs cast and placed, curbing and railing installed) during the calendar month of July, and that the whole structure was built at the rate of more than one mile a month after the equipment was assembled and put into operation. This unusual rate of progress was made possible chiefly because the major portion of the construction was carried on in the yard where manufacturing methods could be employed.

Because of the very heavy loads that frequently are used on precast piles, it is important for the engineer to have definite information on their carrying capacity. Where a large number of tests are required, because of varying and unusual ground conditions, it is found

that a steel tank (Fig. 15) supported by a structural steel framework that fits over the top of the pile, proves very economical for loading and unloading. This tank is filled with water to provide the necessary weight. The derrick scow lifts the tank from one location to another.

Experience in the handling of large precast piles with special apparatus naturally led to the consideration of precast structural units

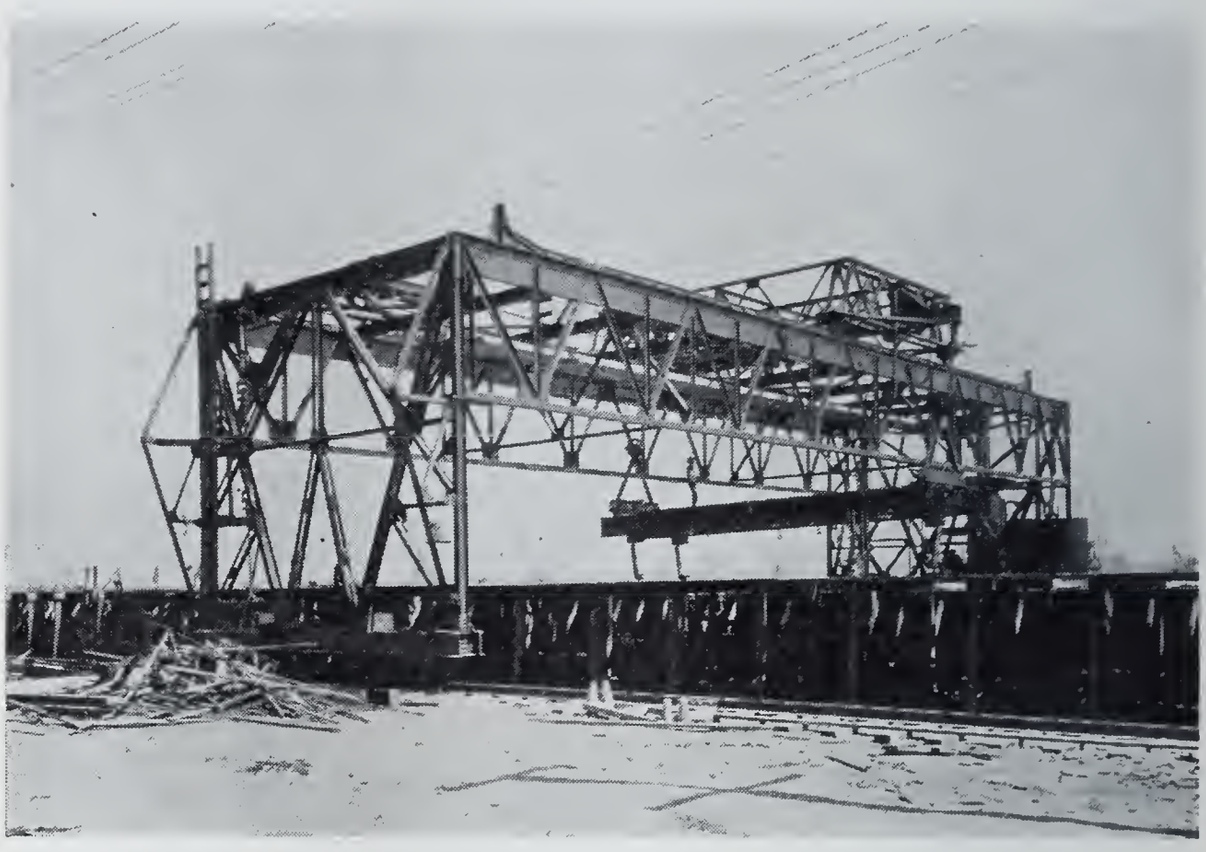

Fig. 15. Gantry Crane and Lifting Device for Precast Slabs.

in the building of structures that have a large number of recurring elements. For that reason a rather unique plan of construction was adopted in the building of the slabs and girders for the San Mateo bridge.

The bridge floor (Fig. 16), which has a roadway 27 feet wide, is divided into two elements, each element consisting of a slab and two beams. Here one of these elements is being lifted from the scow and placed in position by a 100-ton crane. These slabs are placed on temporary blocks resting on the top of the pile caps. Inasmuch as two lengths of spans were used (30 and 35 feet) it was necessary to have a lifting apparatus that would adjust to both dimensions. A 10-inch wall between the ends of the slabs provides space for locking the

reinforcement together and placing the expansion joints which occur every sixth bay. These slabs are placed within a fraction of an inch of the proper position and elevation, and are later set in exact position by means of hydraulic jacks resting on ball-bearing bases which are susceptible of accurate horizontal adjustment. The slabs were placed within 0.05 inch of their theoretical elevation, thereby insuring a perfectly level bridge.

Fig. 16. End of Beam and Slab Construction.

That portion of the casting yard in which the slabs and beams are cast is laid out in a manner similar to that which is used in casting the pile, except that the span of the gantry is much less. The crane itself is considerably more complicated than the pile gantry. Here, too, the same lifting apparatus is provided, with adjustable tongs that engage the slabs at definite prescribed points for which they are properly reinforced. The larger of these slabs weighs about 55 tons, so that the apparatus in itself is of considerable size and strength.

The beam and slab construction is provided with U reinforcement through which transverse horizontal rods pass and lock the two slabs together. The recesses in the face act as a vertical and transverse lock to insure against displacement. The edge of the cantilever con-

struction in the middle of the roadway was formed so accurately that in no instance is the interval between slabs more than a quarter of an inch.

In view of the inaccessibility of the site of the bridge (between two and three miles of marsh intervening beyond the two bridge-heads), and since a channel some four miles long had to be dredged for bringing in floating equipment, the difficulties of supplying large concreting apparatus and of getting men back and forth to take care of the placing and stripping of forms, were all factors which led to the decision that the intricate and involved work, requiring the major portion of labor, should be kept in the Alameda yard, and that as little as possible of the detail work should be handled on the bridge site. This resulted not only in increased speed but in considerable saving over the normal method of handling construction of this character.

All of the above leads us to question whether or not it will be possible, as time goes on, for us to decrease our unit costs and increase the rate of progress by the use of precast methods. Modern and successful contracting now involves the design and building of special apparatus for the economical construction of a specific structure. Such problems are a never-ending source of inspiration to the ingenious and progressive construction engineer.

You here in the Pittsburgh district, where river transportation is rapidly developing, have problems of this character which may well have your attention. I refer to the river-walls which are destined to play an important part in the economic and esthetic development of your beautiful city.

DISCUSSION

C. S. Davis:* All of the piles shown were square. In my experience, hexagonal and octagonal piles are frequently used. I am wondering why Mr. Upson has confined his discussion to square piles.

Maxwell M. Upson: The reason for this is that the pile is designed essentially for handling. This means that the handling stresses are the greatest stresses to which it is subjected. With the

*Consulting Engineer, Pittsburgh.

square pile it is, of course, possible to lift and handle it with a definite knowledge of the location of the reinforcing steel. This means that the stresses can be definitely predetermined. In handling a round or hexagonal pile, the compression area is reduced, which necessitates additional and otherwise useless steel, and the chance of picking the pile up with the wrong areas in compression is materially increased.

EDWARD GODFREY:* In Mr. Upson's paper on precast concrete piles, he has clearly set forth the advantages and the disadvantages of this type of foundation.

Many of the misfits of engineering are the result of men who have a preference for some special type of construction, failing to see the limitation of this product and using it where it is not appropriate.

It is of particular interest to note the advantage of the long, precast, concrete pile over the wooden pile, and, in fact, over any other type where soft ground or mud in deep layers is encountered. The writer was particularly impressed with the information on the 24-inch square pile which was found by test to be good for 50 tons, acting as a pile and a column. This is less than 200 pounds per square inch on the cross-section of the pile. This unit load is so far below the common recommendation of 800 to 1200 pounds per square inch on reinforced concrete columns that it seems sufficient explanation of the fact that foundation engineers are not called on to explain away wrecks as superstructure designers in reinforced concrete are so frequently required to do.

Mr. Upson's description of the curing of concrete piles is very interesting. It is along the line of recommendations that the writer has been making for many years. A continuing moist condition attained by the use of burlap covering, constantly sprinkled, is an ideal condition for the proper curing and hardening of concrete. Occasional sprinkling does not meet the conditions. Only a knowledge of the true nature of Portland cement—a colloid, and not a crystallizing substance—can be a correct guide in the handling of cement and its products. Access of water to the hardening cement causes the colloid to swell and prevents the hair cracks and checks, which Mr. Upson correctly states are absent from properly cured concrete.

*Structural Engineer, Robert W. Hunt Co., Pittsburgh.

Another interesting part of Mr. Upson's paper, and one for the attention of engineers, is the description of the use of spuds to steady the scow in driving the piles in water subject to tides or high waves. The same scheme is used in dredging operations. These four spuds resting on the bottom of the lake or other body of water make of the scow a great table and contribute a solidity not realized in a floating scow.

It would be interesting to know Mr. Upson's experience in the matter of the best weight of hammer in driving heavy piles, and its relation, if any exists, to the weight of the pile.

R. M. Riegel:* Mr. Upson, have you ever developed any system of interlocking sheet-piles to apply to cast concrete? Does your company, in its concrete practice, make use of the modern theories of concrete proportioning?

Maxwell M. Upson: We have a type of pile which has a steel sheet-piling embedded in its edges. These edges act to interlock the different units and make a tight sheet-pile wall. Frequently these sections are so placed with grooves that the steel section can be grouted and protected from the action of rust. This type of sheet-piling has been used in many different places.

I think Mr. Boardman, who is here in the audience, can contribute a good deal of information on this subject, since he has had to do with the selling of the steel sheet-piling which is used for that purpose. I believe that five different sections of sea wall near San Francisco have been built where this type of construction has been used. An interesting installation of this character was made for the New York State Canal Board at Albany. In building a bulkhead they found that the material behind the bulkhead was a fine sand overlying a ledge of rock. The sheet-piles having these interlocking devices were driven down to the rock and doweled into it, thereby securing a firm hold. This doweling was accomplished by drilling a hole in the rock through a three-inch hole cast in the center of the sheet-pile and dropping a steel dowel therein. This structure was put in place some fifteen years ago and I understand is in excellent condition to-day.

*Designing Engineer, Department of Public Works, City of Pittsburgh, Pittsburgh.

C. S. Boardman:* How much penetration was required?

Maxwell M. Upson: These piles were about 35 feet long, penetrating some 20 feet below water at full pool.

C. S. Boardman: Did you jet the piles, or drive them?

Maxwell M. Upson: A combination of jetting and driving, depending upon the material to be penetrated.

C. S. Boardman: Do you follow any definite rule in making the concrete? Can the reinforcing steel not be placed in the pile above the water-line, three inches or more from the surface of the pile?

Maxwell M. Upson: We follow the code set forth by the American Concrete Institute. This involves the use of sieve analysis and trial methods of securing a maximum density. In assembling our mixtures we always keep in mind the workability of the concrete, which, after all, is an extremely important characteristic in its practical bearing on all placing of concrete. On the San Mateo work we put up a laboratory and made daily tests to make sure that the standards that had been determined upon from a long series of preliminary tests were maintained. It is interesting and frequently surprising to observe the improvement in quality, both as regards density and impermeability, and the reduction in cost, attainable by careful laboratory experiments. In this instance, the strength of the concrete was increased almost 50 per cent. over the standard prescribed mix, and some $30,000 was saved in the cost of cement. I have knowledge of one contract where $100,000 worth of unnecessary cement was used. In addition to the waste of money, the excess cement caused excessive brittleness, which will result in very serious repairs inside of ten years. It is of the utmost importance that the engineers and contractors work together in order to improve the quality of the product and at the same time save unnecessary costs.

C. N. Haggart:† I should like to ask whether you had to shorten or lengthen any of these piles, and to ask something about the process.

*Contract Engineer, Jones & Laughlin Steel Corporation, Pittsburgh.
†Consulting Structural Engineer, Pittsburgh.

MAXWELL M. UPSON: A large percentage had to be cut. A great many thousand dollars were spent in tests. We drove test piles every 250 feet over a distance of about 7¼ miles. These tests were made to predetermine the casting length. Even with this frequency there was a wide variation in the lengths used as compared with the lengths indicated by the tests. This necessitated the carrying in stock of varying lengths of piles, so that, as ground conditions changed, piles would be available to meet the varying demands. Sometimes this necessitated keeping two or three scow loads of piles available near the pile-driver.

The cost of cutting off piles is very great, particularly when a scientifically mixed concrete is used. The cutting is done by men working from chairs slung from the reinforcement which extends out of the top of the piles. They use air hammers and burn off the steel. It is really necessary to see a 24- by 24-inch pile to realize its true magnitude.

IMPORTANCE OF RIVER TERMINALS AND DOCKING FACILITIES IN THE DEVELOPMENT OF RIVER TRANSPORTATION*

By E. K. Morse†

At 2:15 A. M., March 15, 1907, the United States government recorded the highest flood at the Point in Pittsburgh, of which there is any authentic record. The gage reading at the Point was 35.5 feet which, reduced to government elevation, was elevation 732.5 above sea-level at Perth Amboy, N. J. There are 218 acres in the "central business district" of the City of Pittsburgh bounded by Grant Street, Tenth Street, building lines on the Allegheny River from Tenth Street to the Point, and from the Point up the Monongahela River to Grant Street.

The flood of March 15, 1907, flooded 41 per cent. of this area and at Horne's store at the corner of Penn Avenue and Stanwix Street there was a depth of three feet of water over the sidewalk. The whole of the lower part of the North Side below the Fort Wayne Railroad and Monument Hill was flooded. The direct loss within this district from the flood of March 1907, was $6,000,000. The Inland Waterways Commission estimated the losses on the Ohio River from the Point to the Mississippi at Cairo, a distance of 966.8 miles, as $100,000,000.

It is unfortunate that the American people have to have a calamity before they can arise to the occasion. It was the disastrous flood of 1907 that caused the Chamber of Commerce of Pittsburgh to organize what is known as the Pittsburgh Flood Commission. No similar organization in the United States has done as good work or as much work as the Pittsburgh Flood Commission. No other publication on the subject has been as thorough and comprehensive as that issued by the Engineering Committee of the Flood Commission of Pittsburgh, published April 12, 1912. These engineers labored from 1908 to 1912 devoting an enormous amount of time to the compilation and publication of a report containing 975 pages besides an additional publication of a very valuable set of maps. Their time,

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†Consulting Engineer, Pittsburgh.

labor and expense were given free of cost to the City of Pittsburgh. Their first thought was flood protection for Pittsburgh, but before the first year had passed they realized that their slogan should be not flood protection but flood prevention. Their published report followed along these lines and their activities have supported the same thought and aim ever since. They recommended the construction of 17 reservoirs in the Allegheny and Monongahela river basins, which comprise an area of 18,920 square miles—nine per cent. of the total drainage area of the whole Mississippi River basin which is 210,000 square miles. Under the heading of flood protection for the City of Pittsburgh, walls for the city and the North Side were recommended.

In 1925, the engineers of the Flood Commission of Pittsburgh submitted to the City of Pittsburgh plans and estimates calling for a relocation of the harbor lines, designs for a river-front flood wall for the city including the North Side, lateral sewers to intercept the sewers now emptying into the Allegheny and Monongahela rivers, and a terminal for river transportation. The Mayor and Council were urged by the Flood Commission to make a thorough investigation of river-front improvements and adequate provision for modern river transportation. The Mayor and Council have instructed the Department of Public Works to proceed with a thorough investigation, and have appropriated sufficient money to complete this work. This study is under the direct supervision of Director E. G. Lang and Chief Engineer Charles M. Reppert.

In September 1927, careful inspection was made of the river terminals at St. Louis, Cairo, Memphis, and Helena, on the Mississippi River. At every point visited, except that at Helena which was of very recent construction, discarded machinery and equipment showed clearly where many expensive mistakes had been made and some of them repeated. It was made very clear that there can not be a model that will fit all conditions. In fact, the traffic at every port should be analyzed to meet the respective conditions at each and every specific location.

There are two distinct classes of commerce on the Mississippi River. First, there is the promiscuous shipment of package and freight received and dispatched by packet-boats and barges. This is received and dispatched at a wharf connecting directly with the warehouse.

This commerce may be received and dispatched from the warehouse by rail or by truck. This type of commerce is much the same as has been received and shipped from wharf-boats on the Monongahela wharf in Pittsburgh. The second and most important is river-to-rail tonnage, which comprises freight by rail and by river transportation and is transferred directly from the one to the other and not stored in warehouses. This classification is for heavy tonnage and is by barge only.

Traveling cranes at the terminal warehouse at St. Louis handled all the commerce to and from the packets and barges. Cranes handled loaded trucks to and from the warehouse to the barges. At East St. Louis, where the river-to-rail terminal was located, a traveling crane was installed for hoisting material too heavy to be trucked by hand. At every warehouse terminal, inclined hoists should be installed of sufficient capacity to haul train loads of loaded warehouse trucks from the barge or packet to the warehouse and from the warehouse to the barge or packet-boat. Each incline should have two tracks equipped with link-belts driven by electric power and reversible so that both tracks could be operated up or down at the same time, or one up and the other down at will and at different speeds depending on the load carried. There are two principal reasons why packet business on the upper Ohio River has not been profitable.

1. The shipper was not adequately protected from loss.

2. The commodities transported by packet-boat were loaded and unloaded by hand and were often carried a distance of 150 feet.

One of the most modern, old-fashioned wharves is the Monongahela wharf just below the Smithfield Street bridge in Pittsburgh, and although that wharf has a paved highway leading from the wharf-boat to Water Street it was always a hard pull for horses, and even with trucks there is grave danger of skidding on ice-coated pavements (the author saw from his office in the Conestoga Building one winter morning, two trucks slide down the wharf at the foot of Wood Street into the Monongahela River inside of thirty minutes). The modern terminal warehouse must be above high water. The handling of material must be by power. The transporting of goods in the warehouse must be on modern ball-bearing trucks, hauled by gas-engines.

At Helena, the warehouse floor is a reinforced concrete slab almost as smooth as a hardwood floor in a private dwelling. Often

two men were observed pushing trucks loaded with four or five bales of cotton to the top of the incline but not until ten or twelve trucks were assembled were they pushed on to the incline and thence lowered to the landing below and hauled over into the barges with a little dinky gas-engine. Each truck had a load of cotton weighing from 2000 to 2500 pounds. Apart from a few independent packet-boats on the Mississippi River, the barge transportation from St. Louis to New Orleans in 1927 was handled by the Mississippi-Warrior Transportation Service under the jurisdiction of the United States government.

The railroads in the vicinity of Pittsburgh have not yet evidenced interest in river transportation. One of the principal reasons is that the railroads held themselves responsible to the shipper for all rail tonange, while shipment by river carried no guarantee of safe delivery. River consignments were at the shipper's risk. Inquiry at the offices of the Mississippi-Warrior Transportation Service at St. Louis revealed the fact that all bills of lading contained a clause guaranteeing the shipper against any and all losses in river transportation just the same as has been the practice of railroads for many years past.

It was very interesting to find that there is the best of feeling and relation between the railroads and the Mississippi-Warrior Transportation Service, and that there is a growing business of river-to-rail transportation. The railroads were friendly because they had learned by actual experience that they were getting, by river, freight which they would have otherwise never received, and the barge lines were getting freight for river transportation from the railroads, which they could never have obtained any other way, while the shipper could bill goods from river points to destinations inland by rail and vice versa with the same confidence of delivery and protection against loss as has been the custom on all the all-rail routes.

This has been made possible by a ruling of the Interstate Commerce Commission which compels the railroad to receive freight by river shipment and compels the river transportation company to receive freight from railroads. Both have found this interchange of business lucrative, notwithstanding that the Interstate Commerce Commission has ruled that 80 per cent. of the freight rate goes to the railroad and 20 per cent. to the river transportation agency. That

is a distinct discrimination against the river interests. At this time there are large shipments of steel products from Pittsburgh down the Ohio and the Mississippi as far as New Orleans made by the Carnegie Steel Company and the Jones and Laughlin Steel Corporation which own their own fleets and their own terminals. When the locks and dams on the Ohio River are completed, either in the fall of 1929 or the summer of 1930, there will be all-year transportation on the Ohio River from Pittsburgh to Cairo. The federal government will have then spent over $100,000,000 in the canalization of the Ohio River. During the fall of 1928, transportation was started from St. Louis to St. Paul under government support. It is expected and believed that this will open up very lucrative interchange of commodities. The season will naturally be short and the depth of the river in the autumn would limit barge loads to five-foot draft. Transportation on the Ohio River will be continuous throughout the year. Most of the year there will be nine feet of navigable water with a possible limit of seven feet during certain periods of dry seasons.

During the autumn of 1908, and again in 1928, when there were months of drought that caused the lowest recorded flow of water out of the Allegheny and the Monongahela rivers, it is questionable if there would have been sufficient flow of water in the upper Ohio River for continued lockage. It is at such times that there would not be more than seven feet over the miter-sill in the locks and pools in the Ohio River. As a matter of fact the low-water condition in the fall of 1928 was within 0.3 of a foot of that in 1908.

It is always a problem to know what kind of freight can be expected from down-river ports to the up-river sections, and it is just as difficult to know what volume and character of tonnage would be developed if there were adequate facilities with the most modern methods of handling freight and packages for down-river transportation. These are conditions that must be carefully considered before completed plans and equipment are designed for modern terminals.

During the inspection from Cairo to Helena, an immense amount of discarded machinery representing heavy losses was too often in evidence. Such graveyards must materially affect the net earnings, especially if these losses are written off and covered up by charging them to transportation for a term of years.

Handling of river-to-rail tonnage on the Mississippi has been economical, but the cost of handling the tonnage and promiscuous merchandise to and from the warehouse has been unduly expensive. In one of the ports inspected in September 1927, the changing of links in the "Link-Belt" conveyor to meet the fluctuating height of the river, cost on an average of $20 for every day that it was operated and every time that a link was taken out or one put in, the delay caused was from two to three hours. If a towboat and a fleet of barges with overhead charges of from $100 to $200 a day should be delayed two or three hours on account of changing links, it would be a loss in addition to the loss of $20 that the barge terminal has to meet. An up-to-date terminal would completely eliminate such expenses and delays.

If adequate river terminals are provided for Pittsburgh it is believed that there will be enough freight and merchandise for down-river and up-river shipments to justify the city in the expenditure for one unit of a modern terminal, so located and designed that extensions can be made for additional units as they become necessary. It is further believed that this would develop into a very great distributing point for up-river shipments on both the Allegheny and the Monongahela. If such a development can be made, Pittsburgh would be in the true sense of the term, the Ohio River terminal. There is a feeling in certain quarters that the river terminals should be completely separated from river-front improvements.

The only public wharf in the city is that on the Monongahela River near Smithfield Street.

If a wall is ever built along the river front, a two-unit warehouse terminal can be built below Smithfield Street to take the place of the present terminal; this, however, would be subject to the disadvantage that it would be located in the congested part of the city and could never have rail connection. A river terminal can be built without flood walls around the city, but flood walls around the city can not be built without providing an adequate warehouse terminal for river shipments—a terminal which is located favorably for access by trucks, away from the congested section of the city, yet convenient to every shipper, and with rail connection to the warehouse and to the river front.

If a wall such as recommended by the engineers of the Pittsburgh Flood Commission were constructed along the lines contemplated in the plans made—from the building line along Duquesne Way to the proposed wall along the Allegheny River, and the building line on Water Street to the proposed wall along the Monongahela River—the total area reclaimed would be about 59 acres. This adds 27 per cent. to the present total area of 218 acres in the central business district. The river-front improvement is just as vital to the river interests as the river interests are to the supremacy of Pittsburgh and vicinity. There should be no division of interests, much less any selfish interests.

With unity of purpose, the revision of the harbor lines can be made to modernize the Allegheny and Monongahela rivers. With unity of purpose, the growth of a modern city, of a modern river, and of a modern river terminal can be made and will be made to force the construction of a ship-canal from the Ohio River to Lake Erie. If that be brought about, the supremacy of Pittsburgh will be guaranteed for years. Without unity, there will be a small Ohio River terminal at Pittsburgh; the natural growth of the city will be dwarfed, and there will be no ship-canal to Lake Erie. It seems inconceivable that this opportunity should be lost.

Pittsburgh's river terminals can be and should be made the most important on the Mississippi and Ohio rivers above New Orleans. This would help largely to hold Pittsburgh supremacy. This would also increase the tonnage by rail.

The author makes bold to predict that the day is not far distant when the great trunk-line railroads along our inland waterways will either own their own river fleets or enjoy very close relationship to river transportation companies that will co-ordinate through river and rail transhipment to the mutual benefit of the shipper and the transportation companies.

Great cities are built on bodies of water. Their importance increases in direct proportion to the magnitude of the streams, rivers, and lakes upon which they are located. The continued increase in growth is in direct proportion to the facilities furnished for transportation by water, be that method of transportation marine or inland waterways systems.

By the fall of 1929, the Highway Department of the Commonwealth of Pennsylvania will have, at enormous expenditure, completed primary roads from Pittsburgh to the West Virginia line on the William Penn Highway passing through Steubenville, and to the West Virginia line on the Lincoln Highway passing through East Liverpool. West Virginia has already completed 3½ miles from the state line of Pennsylvania to Chester, W. Va. (across the river from East Liverpool) and has promised to complete the link from the Pennsylvania state line to Weirton, W. Va. (across the Ohio River from Steubenville) by the time Pennsylvania has completed the William Penn Highway to the West Virginia state line. These two highways will connect us east and west with a volume of travel which, during the summer season, is expected to be an increase of more than 8000 pleasure automobiles a day over the present traffic.

The Pennsylvania Highway Department has let contracts on the Lincoln Highway between Pittsburgh and Greensburg during the last year and a half. This work calls for the rebuilding of nearly fourteen miles of highway, almost one-half the total distance from Pittsburgh to Greensburg.

With river-front improvements as above outlined, great by-passes can be provided, and parking facilities furnished on a scale not enjoyed by any other city in the United States. Pittsburgh has an opportunity in this one respect of river-front improvement that any city of her size would give millions to obtain. Such river-front improvement would not only beautify the city but would bring to our merchants and business interests millions of dollars in new commerce which now goes to Cleveland, an average distance of 120 miles as against an average distance of 42 miles to Pittsburgh. It is hardly to be expected that our merchants and manufacturers and those interested in the growth of our city and our terminals will let such opportunities pass.

DISCUSSION

Thomas M. Rees:* I have had experience in navigation on the river for many years past. My father was one of the largest owners of steamboat stock in the Ohio and Mississippi valleys, and myself and my brothers followed him in that line since 1862.

*President, James Rees & Sons Co., Pittsburgh.

I have navigated the Allegheny River from Pittsburgh to Oil City and was director in the Allegheny River Navigation Company, 1865 to 1867, and we had a paved wharf to work on from the alley below Seventh Street to above Eighth Street. You will now find that paved wharf covered by 10 to 15 feet of clay and cinders.

At St. Louis the barge line uses the terminals, but the freight and passenger boats engaged in interstate commerce, both north and south of St. Louis in the local trade, use wharf-boats for receiving and discharging freight, as has been done for many years past at Pittsburgh and all cities on the Ohio River for the local farm and produce trade. The terminal warehouse with elevators has found it more expensive to handle this local trade than the farmers and buyers can afford.

My father was a large stockholder in the Anchor Line, one of the largest and finest lines of side-wheel boats that ever ran on the Mississippi. In 1872 he built on the main wharf at Memphis a terminal warehouse 500 feet long and 300 feet wide, with incline elevator, but it was not a success. It was found too expensive, and it created congestion on the streets leading to and from the wharf, and for the local passenger and freight trade the planters preferred the open wharf and the wharf-boats. The terminal elevator burned down in 1876 and was not rebuilt. The terminal elevator at Memphis is over a mile below the main wharf, and the local freight and passenger boats that handle the trade for one hundred miles up and down the river use the main wharf entirely and have their wharf-boats.

I speak with knowledge, as our Company owns a modern steel wharf-boat 220 feet long and 48 feet wide, fireproof, with 16 water-tight compartments, with 3400 feet of clear deck surface for freight, worth to-day, with outfit, about $100,000. They drive on and unload freight from trucks. I do not think owners of steam vessels engaged in local trade between Pittsburgh and Louisville would be able to compete with railroads and trucks if compelled to pay for the extra handling of freight, as well as warehouse or terminal charges for elevating, etc.

I know of but one city in the United States which has a terminal such as was proposed for Pittsburgh, and that city, owing to its location on a high bank, is compelled to have elevator service entirely, but the service is quite different.

You must look mainly at the service that is required, as formerly the steel-mills and glass-houses in Pittsburgh had their salesrooms and warehouses on the river bank and adjacent streets, and were located in the city. Those mills are now located away from the city on railroads with sidings, and on the banks of the river where they can load directly into cars or boats. The business on our streets is entirely different from what it was fifty to seventy-five years ago, and the mills and factories must have less expensive methods for handling their output. To receive the benefit of water transportation they must minimize the handling of their products, and they must have their own boats and barges, or hire from the modern transportation companies.

We own the largest manufacturing plant in what is now known as the "golden triangle" in the old city and we can not use the Allegheny wharf to-day owing to its condition, as it is not safe for hauling. The city of Pittsburgh, by the change of the street grade, made the grade of Duquesne Way some four feet higher than it is on Liberty Avenue, two squares from Duquesne Way, and this change of grade has not only made it unsafe to life to handle traffic as formerly, but has added an increase of over 30 per cent. to the labor cost, particularly in all our local trade, and this has compelled us to dispose of our plant and withdraw from business entirely.

T. R. Tarn:* I happened to be interested in the barge-line extension between St. Louis and Minneapolis on the upper Mississippi River. A barge-line or a packet-boat without proper terminal facilities is handicapped. I would like to say a word in regard to the design of boats and barges. They must be co-ordinated with any terminal facilities that are under consideration. For instance, on the upper river to-day, they are operating four tow-boats with 60 barges. The barges have a nominal draft of four feet and a maximum of six feet. They carry 250 tons per barge on four-foot draft and 500 tons per barge on six-foot draft.

The barges were designed after a great deal of study as to what should constitute the proper type of barge for the commodities to be handled and the facilities available. As a result of that study a so-called general purpose barge was built. The barges are 126 feet long,

*Naval Architect, Pittsburgh.

26 feet in beam and seven feet in depth. They have a cargo box extending something like 100 feet. Their hatch openings are arranged to suit ramps. The ramps are mechanically operated and they lie between pile clusters and wharf-boats such as Mr. Rees mentioned. From the barges, the freight is handled by means of trucks drawn by small electrically operated tractors to various portions of a warehouse for shipment either by rail or truck.

At the St. Louis terminal, which forms the lower terminus of this line, the power equipment has been supplemented within the last year or two to represent the best that has been built up to this time for handling the numerous kinds of commodities that are offered to this barge-line for shipment. The same is true of the terminals at Burlington, Dubuque, and Davenport, Iowa; Minneapolis, Minn.; and Rock Island, Mo. This was found to be necessary, and the equipment which transports the freight or commodities by river had to be made suitable for the transhipment facilities at the terminals. This same adaptability will be necessary for any terminal built in Pittsburgh. It is suggested that before anything is definitely done in the way of building a terminal structure in Pittsburgh, those interested should visit the terminals on the upper Mississippi River, to gain the benefit of the research work accomplished. It may be that commodities from this port will be shipped to upper Mississippi River ports and require transfer at some of these cities.

During Mr. Morse's talk on the river-wall, it occurred to me, in view of the fact that he stressed the need of Pittsburgh for additional automobile parking space, that the building of a river-wall is a rather expensive means of obtaining the additional parking space, especially since we now have another means of high-speed transportation, the aëroplane. It may be that it would be better to use the additional acreage acquired by building the river-wall for use as a landing field.

Another thought occurred to me. There has been talk of moving Monument Hill. Since we were talking about the devastation due to floods, why not take the material from Monument Hill and raise the low areas above flood level and use the acreage obtained by the removal of Monument Hill as a parking space?

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WASTE HEAT IN CEMENT-MILLS AND PAPER-MILLS*

By H. B. Smith†

The art of reclaiming the heat in waste gases from industrial furnaces had its inception many years ago and was considered possible only from such furnaces as had temperatures ranging around 1700 to 1800 degrees F., or over, and this was one of the reasons why its development was at a standstill for a period of ten years between 1902 and 1912.

The earliest record of a real attempt to study this problem from an operating as well as a scientific point of view was in 1902 when there was installed at Cayuga Lake Cement Company, a water-tube boiler which during 1903 was experimented with and tested by the late Professor Carpenter whose work at that time not only pointed out the possibilities in this class of work but established and gave to us certain fundamental data which may be classed as pioneer work.

That Professor Carpenter's early investigation did not promote immediate development of the waste-heat installation, was not due so much to economic as to physical reasons. The kilns of that era being short were conducive to high exit gas temperatures and a heavy dust loading, which condition, based on our experience to-day, leads us to believe that difficulty was encountered in keeping the first pass of the boiler from plugging up. The available records of his work do not give any details of the trouble and the foregoing statement is merely a conjecture but we do know that the general impression among the cement manufacturers was that a boiler could not be installed back of a cement kiln without impairing the draft which in turn reduced the output. Even as late as 1915 this idea prevailed to an amazing degree.

Another factor which tended to retard the development of waste-heat installations was the progress of the cement manufacturers them-

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†Engineer, Babcock & Wilcox Co., New York.

selves, in that as the standard of cement was raised from time to time, harder burning was required and, in order to minimize the coal consumption per barrel, the length of the kilns was increased, which reduced the exit temperatures from around 1800 degrees to 1400 degrees. With such temperatures the idea was rather prevalent that waste-heat boilers would be an economic failure.

During 1910 and 1911 some boilers were installed in connection with open-hearth furnaces at the Illinois Steel Company, where the gases entering the boiler ranged from 1200 to 1300 degrees F. From extended tests it was conclusively proved, and publicly stated, that the net steam realized from these waste-heat boilers when using so-called low-temperature gas was equivalent, when expressed in terms of a coal-fired boiler, to approximately 250 pounds of coal per ton of ingots. Expressed in another way, this saving was equivalent, at that time, to a saving of 20 to 25 cents per ton of ingot.

The published results from the Illinois Steel Company tests so increased the interest of the industrial furnace users as a whole, that at the end of the next ten years, that is, up to and including 1923, there had been installed with the various types of industrial furnaces a total of 175,000 boiler horse-power.

For the present year it is estimated that the cement industry of the United States has a capacity of 227,000,000 barrels as against 20,000,000 barrels for 1903, or an increase of 1000 per cent. During this same period the apparent increase in kiln capacity with waste-heat installation equipment is 65,000,000 for 1928 and 180,000 for 1903, or an increase of 11,000 per cent.

The cement manufacturers to-day probably effect a greater saving than any other one industry for with their 65,000,000-barrel rated capacity and a probable output of 50,000,000 they are generating 555,000,000 boiler horse-power hours, which is equivalent to that producible from 1,000,000 tons of coal a year.

It is interesting to compare tests of waste-heat installations 20 years apart. The first test in 1903, as reported by Professor Carpenter, has been modified somewhat by using the specific heats used to-day. The second test represents actual operating conditions in that it extended over a considerable period of time with periodical checking of the recording instruments.

	—Date of test—	
	1903	1923
B.t.u. fired to kiln per barrel	1,247,958	1,121,893
Gases leaving kiln, degrees F	1820	1250
Pounds gas per pound coal	20.0	17.7
Pounds gas per pound clinker	1780	1551
Total gas per hour	27,749	101,250
B.t.u. per pound of gas above 200 degrees F.	484	295
Total heat absorbed by boiler and economizer—B.t.u.	9,977,326	20,206,130
Per cent. available heat recovered	54.6	67.9

The percentages of heat recovery given above are not to be taken as efficiencies for those determinations have been made on the basis of 200 degrees F., the temperature of the feed-water to the economizers in both tests. The percentage of recovery will, within limits, increase as the temperature of the feed-water is lowered.

If, in the 1923 test the entering gas temperature had been 1820 degrees F. instead of 1250 degrees F., the percentage of heat recovery, because of proper arrangement of the heating surface to obtain the maximum by both radiation and convection, would have been 82 per cent. instead of 67.9 per cent, an additive gain of 14 per cent. This 14 per cent. then is, in a measure, the advancement in the art and 82 per cent. recovery is about the maximum to be expected unless an air preheater is used in addition to a boiler, superheater and economizer. It is doubtful if air preheaters will ever be widely used in cement waste heat because of available heat adjacent to the point of consumption, which heat is readily converted for combustion purposes.

When designing an installation to recover the heat in the gases from any type of commercial furnace, first consideration must be given to continuity of service and flexibility. A 24-hour delay in the output of such furnaces may wipe out the economies of an entire month. Too much consideration can not be given to the draft loss, for upon it depends the successful and efficient operation of the primary furnace, the net steam output and the life of the induced-draft apparatus.

Draft loss is increased by air infiltration into the system, improperly designed flues, and too many turns and eddies. Gas velocities are also an important feature of the design.

Whether or not a waste-heat installation may be commercially justified, depends upon the cycle of the furnace in question, the temperature of the gases and the cost of purchased power.

In general, it can be said that if the gas temperature is 1000 degrees F., or under, that unusual circumstance would necessarily prevail to justify waste-heat boilers. An example of such a case is one in which the Babcock & Wilcox Company was asked to supply some boilers to generate, with gas at 800 degrees F., sufficient steam to operate gas-producers supplying gas to the furnaces, which producers were made necessary because of a shortage of natural gas with which the furnaces had been fired prior to that time. Under these conditions and by the use of 20-high horizontal-tube boilers there was generated a surplus of superheated steam when operating gas-producers, steam-turbine-driven induced fans, and soot blowers. Another case where boilers have been installed for gas less than 1000 degrees F. is in process work where the gases must be cooled before being passed on for further processing.

Unfortunately, little information is available regarding the cost of producing a kilowatt in any of the plants where the entire plant power is produced from the waste gases, but it is generally accepted that the cost is, by an appreciable margin, below that of purchased power. A goodly number of the cement plants are self sustaining as regards power and one plant whose identity can not be divulged is producing steam at a cost of 10 cents per thousand pounds per year, which cost is made up as follows:

Interest and depreciation.....	0.074
Operating labor and supplies.....	0.018
Repair labor and supplies.....	0.008
	0.100

It will be noted that 74 per cent. of the total cost is for interest and depreciation which is from two to three times the cost for central stations. This is necessarily true because a waste-heat boiler system with its collecting flues, dampers, dust hoppers, and screw conveyors, etc., costs about as much per rated horse-power as does a coal-fired boiler, yet the former operates at only 75 per cent. of rating, whereas the latter may operate at three and sometimes four times this rating,

which gives an extremely high rate of steam output per rated boiler horse-power.

At the present time between 60 and 70 cement plants have waste-heat boiler equipment aggregating approximately 150,000 rated boiler horse-power and probably 35 per cent. of these plants are self sustaining. Such plants as do not obtain all the necessary power from their installations probably have a high steam rate in the generating equipment or a high power consumption per barrel of cement. There are some plants obtaining as high as 4.8 pounds net steam from and at 212 degrees F. per pound of coal burned in the kiln, though the average net is probably 3.5 pounds. If a plant consumes 110 pounds of coal per barrel and obtains 3.5 pounds of steam from and at 212 degrees F. per pound of coal, there are available 373,600 B.t.u. per barrel of cement which, with modern generating equipment, should produce 25 kilowatts per barrel, or a surplus over that which some of the more modern plants require even with the advent of the higher grade of cement which requires finer grinding.

A power generating station for a 4500-barrel plant using 110 pounds of coal per barrel burned under the dry process would consist of:

Three boilers, 9400 square feet each.
Three economizers, 3300 square feet each.
Three motor-driven direct-connected induced-draft fans.
One stand-by boiler, 5000 square feet.
Two turbines with auxiliaries of 3000 kilowatts capacity each.

The probable cost of the waste-heat plant complete, including building, would be $330,000, or $100 per rated boiler horse-power. The generating station would cost approximately $415,000, making a total of $745,000, or $126 per rated kilowatt.

A plant of this description when handling 90 per cent. kiln production, or 300,000 pounds of gas per hour at 1300 degrees F., would produce 69,000 pounds net steam per hour at 225 pounds pressure and 100 degrees superheat, if the feed-water to the economizer is 200 degrees F.

The average operating charges for such a plant would probably be:

Operating labor	$ 30,000
Supplies	4,000
Maintenance	13,000
Technical supervision	6,000
Fixed charges, 13½ per cent	101,000
	$154,000

With a net steam output of 69,000 pounds per hour, such a plant should generate 4000 kilowatts, which would put the power to the switchboard at a cost of 4.4 mills. The actual cost per kilowatt, however, will exceed this in a cement plant equipped with modern and efficient grinding machinery, for the probable load, based on 19 kilowatts per barrel, would be 3200 kilowatts at 90 per cent. production, in which case the cost would be 5.5 mills.

Whether or not a coal-fired stand-by boiler should be included in the steam-generating equipment depends upon the cost of maintaining a power connection to an electric generating station. Generally speaking, it is cheaper to install the boiler. Rarely ever is such a boiler used longer than is required to clean a waste-heat unit or perhaps during an extremely active market when a cement plant grinds and ships considerably beyond its daily burning capacity.

In some instances a customer advances the idea of designing a combination waste-heat and powdered-coal-fired unit, but such a combination can not be expected to operate with any degree of satisfaction. From such an arrangement difficulty with draft control will be experienced and the boiler furnace temperature will be increased to and beyond the fusion point of the dust in the waste gases causing a plugging up of the first pass.

The source of greatest trouble in the operation of a cement waste-heat installation is the induced-draft fans, the life of which no one is able to predict, because the nature of the raw material governs the amount of "carry over" and its abrasiveness. The life of fans as reported by the Committee on Conservation, of the Portland Cement Association varies from three weeks to three years. During the last few years material gain has been effected by installing cast-iron liners in the scroll of the fans and very recently several of the users of these fans have found, even though the cost is rather excessive, that plating

the fan-wheel blades with stellite is an economical process. This plating is applied, both electrically and with acetylene gas, on only that portion of the blades where the abrasion occurs.

An investigation of the life of fans in various cement plants shows conclusively that such plants as are obtaining comparatively long life from the fans are scientifically watching the excess air in the kilns and the air infiltration along the system. A kiln and waste-heat unit may be designed for a given output per day but if the excess air is not kept down to a reasonable minimum the gas velocities are increased to such a point that the maximum dust-carrying capacity of the gas may be reached, causing not only undue wear on the fans, but, in a great many cases, an almost prohibitive power consumption to drive the fans.

As has already been stated, the excessive wear of fans, with the attendant short life, was, from the beginning of the cement waste-heat industry, the greatest source of worry to both manufacturer and operator. The Babcock & Wilcox Company gave careful study to this particular point and long since has realized that for a given initial plant cost and given steam output a type of boiler with a lower draft loss would have to be developed before any great relief from fan troubles would be realized. To this end the Babcock & Wilcox Company made use of knowledge gained from several six-drum Rust boilers and developed what is known as the five-drum Stirling. This boiler has exceeded expectations as a heat absorber per square foot of heating surface and reduced the fan power, for a given steam output, from 35 per cent. to 40 per cent. below that required to furnish draft for a Babcock & Wilcox 24-high horizontal-tube boiler. This boiler has several distinctive features, such as an unusual amount of heating surface per square foot of floor area, all metallic baffles which reduce maintenance. All tubes are vertical hence less liable to become dust laden, and, further, all tubes are 3¼ inches in diameter which tends to increase the heat transfer rate.

That further advancement in the design of waste-heat boilers to handle dust-laden gases is possible is borne out by some tests of a two-inch vertical-tube single-pass boiler. This boiler under operating conditions far worse than can be found in cement work gave a heat transfer rate of 6.23 with a draft loss of 0.34 inch. Based on this performance the Babcock & Wilcox Company is offering at

the present time a single-pass three-drum boiler with 2½-inch vertical tubes, entirely inclosed in an air-tight steel casing inside of which is a layer of insulation, such as fire backing and a special refractory which rests against the tubes. For a given steam output this boiler will have a draft loss of about 60 per cent. of that in a Babcock & Wilcox horizontal-tube 24-high boiler.

From a steam generating point of view the most severe conditions under which waste-heat boilers are operated are in connection with gas generating sets. These gas sets, depending on the kind of gas manufactured and the method of operation, vary in cycle so that the boiler receives gas periodically under a rapid increase in both temperature and pressure. Such conditions obviously create an evaporation which increases at a rate considerably in excess of that in a coal- or oil-fired boiler. This intermittent high steaming rate is accompanied by a fluctuating drum pressure which, in some installations, creates a 30- or 40-pound rise and fall in drum pressure during a period of 15 minutes. Naturally, such a variation in steam pressure would make unsatisfactory turbo-generator operating conditions but by having a plurality of gas sets equipped with boilers and overlapping the cycle the main steam line pressure curve is flattened out.

Operating conditions such as have just been cited should be accompanied by the best feed-water conditions possible, but even there considerable apprehension on the moisture in steam delivered by the steam and water drum is only natural. The Babcock & Wilcox Company has a number of these installations, and without any complaints regarding moisture in steam.

One of the more recent industrial uses of the waste-heat boiler is in connection with pulp and paper manufacture, particularly in the sulphate process—a process which a company could not operate unless 70 to 75 per cent. of the chemicals were recovered.

In the process of digesting wood there is remaining in the vats a mixture of 76–78 per cent. water, 14–15 per cent. organic matter and 9–10 per cent. ash. This is known as black liquor. The recovery of the chemicals from the liquor in the past has been accompanied by objectionable odors. This feature has been such a disturbing factor to the pulp- and paper-mills that quite recently there has been perfected a method which replaces the old type of disk evaporator, is more efficient, and permits higher concentration. With the newer

type of evaporation the waste gases are available for direct generation of steam. In a recent installation, at Longview, Wash., a waste-heat boiler was connected to an incinerator designed to burn the black liquor resulting from the manufacture of air-dry pulp, but before the liquor could be burned through spray nozzles it had to be passed through a dehydration process which reduced the moisture content from 76–78 per cent. to 20–25 per cent. The combustion in the incinerator is accompanied by injection of salt-cake, all of which produces a temperature varying from 1900 to 2100 degrees F. From the bottom of the incinerator the melted chemicals flow off. These melted chemicals, commonly called smelt, are primarily the product the paper company wishes to recover.

The waste gases from the combustion of the black liquor are passed through a Stirling boiler having 5562 square feet of heating surface from which the company receives between 17,000 and 18,000 pounds of steam, from and at 212 degrees per hour. The boiler is served by a stack which produces 0.5-inch draft at the boiler damper.

This type of waste-heat recovery is somewhat new and the problem primarily was one of selecting a boiler adapted to lessen as much as possible the difficulties to be experienced in handling hot gases laden with what the paper companies call "carry over." This "carry over" contains 20–22 per cent. insoluble and 78–80 per cent. of sodium in various compounds and if allowed to come in contact with cooling surfaces on which it can lodge it will deposit a hard clinker foundation which is difficult to remove. With this knowledge available the Babcock & Wilcox Company offered a Stirling type of boiler bringing the gases in at the top of the first pass, thereby providing a spacious precipitating chamber in which this clinkering mass is deposited. After a continuous run upwards of two weeks, the clinker in the bottom of the boiler furnace will be from two to three feet deep, after which time it may be removed by burning oil in the boiler furnace to melt the clinker, in which state it will flow out of a taphole arranged in the side wall of the boiler furnace.

That portion of the "carry over" that does not precipitate in the boiler furnace is mainly sodium sulphate and readily removed from the boiler heating surface by soot blowers using steam or air.

DISCUSSION

WILLIAM BRADFORD:* The paper just presented gives us a very concise and at the same time a very clear outline of development, as well as a summary of the present-day problems confronting both the designer and the operator.

In the beginning, let me acknowledge a debt which we owe to the pioneers in this development. The author has outlined Professor Carpenter's early experiments at Cayuga Lake which blazed the trail for later developments and were of the greatest value. There is, however, one other whose pioneer work not only in the field of waste-heat recovery, but in the whole field of combustion and heat transmission is recognized by all as one of the most valuable contributions to the art. I refer to Mr. John E. Bell whose untimely death four years ago robbed the profession of one of its brightest lights. The paper presented by him before this Society more than ten years ago still stands as an authority on the theory of heat transfer.

Mr. Smith has given us some very interesting figures on investment and operating costs for complete cement-mill, waste-heat plants which check very closely with figures which we have compiled from our own experience. It is of course true that accounting methods vary in different companies, but I believe the figures given by the author—4½ to 5½ mills per kilowatt-hour—are a very fair average for the total operating cost, including interest and depreciation on the complete plant, together with the cost of operating and maintenance.

With regard to the question of auxiliary or stand-by service, I want to second the author's remarks as to the dangers of attempting to burn additional fuel in the waste-heat system during regular operation. If this fuel is burned with the low percentage of excess air necessary for efficient operation, the temperatures produced are above the fusing point of the dust, and are bound to result in trouble with plugging up of the first pass of the boiler. Again, if an attempt is made to reduce the temperature resulting from burning of this excess fuel by using a large amount of excess air, there is a possibility of obtaining incomplete combustion with the result that some of the unburned hydrocarbons may be condensed on the first few rows of tubes in the boiler where in combination with the cement dust it will

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form a sticky deposit very difficult to handle. These conditions, of course, apply only when an attempt is made to burn excess fuel during regular operation, mixing the products of combustion with the waste gases from the kilns. If arrangements can be made to cut off one of the boilers from the rest of the waste-heat system, and use it as a direct-fired boiler, none of these troubles will, of course, be experienced. This has been done in a number of installations either by the installation of grates beneath the first pass of the boiler, or by the installation of a damper by means of which a portion of the main flue can be cut off and used as a pulverized-fuel furnace. In general, the installation of an entirely separate coal-fired boiler unit is probably the simplest solution of this stand-by service problem. This, however, involves considerable added investment, and under normal conditions this unit is idle the greater part of the time.

Within the last year there seems to have been a trend in another direction in the solution of this stand-by problem. I know of at least four mills which have been able to work out very favorable reciprocal contracts with the power companies, whereby they are permitted to feed back into the power company's lines excess power generated during their periods of regular operation, and thus build up credits to offset demand charges and cost of energy required for stand-by use.

In pointing out that continuity of service is the first requisite, the author touches one of the vital problems of design. It must be continually borne in mind that the primary object in the cement-mill is the production of cement, and that the waste-heat plant is purely incidental, and must be so designed and operated as to interfere as little as possible with this main object. There must be reliability, coupled with proper flexibility to permit the cutting in or out of various units of the waste-heat system for maintenance purposes without interfering with kiln production. To this end, there have been incorporated in the Edge Moor waste-heat recovery system a number of special features, the principal ones being:

1. A common collecting flue into which the gas from all of the kilns is discharged and passed on to the several boiler units. By the use of suitable dampers between the kilns and this main collecting flue, and between this flue and the boilers, it is possible to cut any of the kilns or the boiler units in or out without affecting the clinker production, or interfering with the operation of the rest of the waste-

heat plant. By a proper proportioning of the openings between this main flue and the individual kilns, it is possible to regulate the draft on each kiln even in plants where kilns of different sizes are connected to the same main flue.

2. A common fan flue into which the gas from all of the boilers is discharged and from which it is drawn by one or more fans and discharged to the atmosphere. Again by the use of dampers on the individual boiler outlets and the fan inlets, it is possible to cut any of the boilers or fans in or out without interfering in any way with kiln production. With the fans operating in parallel on this common fan flue, it is possible to provide a single spare fan which can be cut in in place of any one of the fans requiring repairs. The cost of this one spare fan is a very small part of the total cost of the plant, and we believe is an investment which is fully justified.

The problem of protecting the fan from excessive wear is one which has been given a great deal of study and by the use of properly designed wearing plates in the fan housing and the use of large fans of lower speed, the life of fans has been materially increased in recent installations. In our opinion this is the proper approach to this question, as we do not feel that it is desirable to change the boiler design, with a possible reduction in efficiency, in order to give the fan more favorable operating conditions. Preferably the design of the fan should be such as will give the longest possible life and at the same time permit renewal of worn parts rapidly and inexpensively.

Another phase of the fan problem, and one which should be given very careful consideration, is the selection of fans of sufficient capacity both to meet the extreme conditions of present operation and to provide for future possible increased demands. With the installation of a waste-heat system, it is possible to regulate the draft on the kilns much more closely than when dependent upon a natural-draft stack. This immediately introduces the possibility of increasing the clinker-burning capacity which, in turn, results in increased quantities of gas to be handled by the fans. Our experience indicates that this is almost a universal procedure and must therefore be taken into consideration in the initial fan installation. As a striking example of the possibilities along this line, I have in mind a plant which has been able to increase its daily clinker output from 5800 barrels to approximately 8000 barrels a day without the addition of any more kiln capacity, but

simply by proper regulation of the draft, and increase in feed of coal and material. This, however, is a problem which must be very carefully studied for each individual plant, and I do not want to give the impression of promising or predicting anything like 30 per cent. increase in clinker production by the installation of a waste-heat plant. In practically all cases there is a sufficient return to justify such an installation without bringing in this added and incidental advantage.

In his discussion of the possibility of installing waste-heat equipment on low-temperature gases, the author failed to bring out one point which works in favor of the waste heat in the cement industry. This is the fact that the low-temperature gases are the result of wet-process production, but the low temperatures are offset in this case to a large extent by the increase in gas quantities, and the greater specific heat of the gases due to the greater percentage of superheated steam in the gases. We have a number of installations operating in wet-process mills with gases averaging below 1000 degrees and still providing all of the steam required for the operation of the plant.

W. P. Rice:* The waste-heat proposition in connection with cement-mill operation is a most interesting one, and I might here say that the installation at the plant of the Crescent Portland Cement Company was one of the first to be installed in the cement industry.

At the beginning we did not know all about waste-heat operation. In fact we were barely able to produce enough steam, for a considerable period, to run the turbines driving the fans. These turbine drives were later changed to variable-speed motor drive, however; and, by experimenting and making various changes, most of the obstacles have been overcome. The development of waste heat is now at a much higher standard and we are approaching a point of very good efficiency.

If we deducted steam required for power outside our cement-mill, we would have ample production to operate the entire plant. We are quite fortunate in having an auxiliary stoker-fired boiler plant, part of which we were forced to make use of part of the time, but we are getting to the point where we will very probably cut out the auxiliary boilers and replace these by the use of powdered coal in the main flue as a stand-by.

*Superintendent, Crescent Portland Cement Co., Wampum, Pa.

In Mr. Smith's paper he states that it is inadvisable to use powdered coal in the main flue. Under certain conditions this is true, but at the present time we are planning to build a combustion furnace at the end of the main flue and insert a coal burner therein. The point was brought out in the paper that the temperature of the gases from powdered coal would be much higher than the waste gases from the kilns, which would result in raising the temperature of the entire main flue above the fusion point of the dust deposited in the main flue after being drawn back from the kiln. This is quite true, but we have planned to overcome this difficulty, also. The temperature of gases from the kilns runs about 1400 to 1800 degrees, while we could expect a temperature as high as 4000 degrees from the powdered-coal furnace.

We have at our plant five boilers, and our plan is to narrow down that part of the main flue between the two end boilers so that a reasonable sized damper can be inserted, if necessary, to make repairs on brickwork; and, in addition, to run an air duct from the discharge of the waste-heat boiler fan to the outlet of the combustion furnace, to cool the gases to a lower temperature. By our arrangement, however, we might expect most of the gases from the powdered-coal furnace to enter the boiler at the end of the main flue and not intermingle with the kiln gases.

One of our greatest difficulties at times was the deposit of coal ash on the boiler tubes, but by putting it up to the kiln burners to burn coal only to make clinker, and not be influenced by a zealous boiler operator who would request more heat, this problem has been practically eliminated.

It might be interesting to know that at our plant with the addition of waste-heat boilers and fans rather than the use of stacks we require about ten extra pounds of coal per barrel of clinker. However, with the resultant better draft control we are able to increase the production of clinker—which is, of course, a big advantage—and still produce steam for power purposes.

Fan trouble has been spoken of as the greatest weakness in the waste-heat boiler plant. There is one relief for this, and that is to use the double-inlet fan of low speed and large volume. We have found that it would not pay to "stellite" fan blades in our case, but for a long-continued operation it is very advisable.

I would like to hear from some of you as to your opinion of the bent-tube as compared with the straight-tube boiler. I have been to several waste-heat plants in connection with cement-mills, and have seen some very fine installations, but at no place were the gas temperatures constant. It has always appeared to me that it would be a hard job to keep a bent-tube boiler tight.

If we increase the cement kiln it does not necessarily follow that we increase economy. It might be that you could burn about so much fuel in a given space and have increased economy, but it does not follow that that would increase the output of the kiln. The function of the fan, to my mind, does not enter into that except as it gives steady and uniform draft.

H. B. Smith: We have not experienced any particular difficulties with the bent-tube boiler in waste-heat work where fluctuations exist in temperature of the entering gas. One of the oldest types of waste-heat installation we have is with copper reverberatory furnaces. This type of furnace operates with a comparatively high exit-gas temperature which varies over a considerable range. The operators of these reverberatory furnaces have not, up to the present time, been inclined to give any consideration to a horizontal-tube boiler.

F. Falla:* The draft produced by a stack attached to a cement kiln is by no means uniform. The variations of this draft can be traced to atmospheric changes or variations in the rate at which the fuel is being fed.

The atmospheric conditions are beyond human control and therefore, whatever effect they have on the draft of the stack, it is not subject to the control of the operators.

The variations of stack draft, due to changes in the fuel, are traceable to the irregularity with which the coal is being fed. The coal feeders now generally used consist of a simple screw which is intended to fit closely in its casing and to rotate at the uniform speed desired. These coal screws apparently should take constant amounts of coal but, as a matter of fact, they do not. The amount of coal fed to these screws is dependent upon the roughness of the parts forming

*Engineer, Edge Moor Iron Co., New York.

the casing of the screw, the amount of moisture in the coal, the height of the coal in the bin, etc. It is easily realized that these coal screws may feed from 95 to 105 per cent. of the coal intended to be fed—variations which are not controllable and are not noticeable to the operator. The cause of these small variations is roughness of the design of the screw. As proof of these variations, practice has shown that no two subsequent gas analyses of the kiln gases are ever alike in oxygen content.

A slight change in the coal fed at the burners will unbalance the combustion conditions inside of the kiln shell which in turn changes the temperature conditions at the base of the stack. If the variation of the coal is towards the excessive side, combustion will take place at the base of the stack, and this will increase the temperature of the gases inside the stack and therefore increase the draft produced by the stack. By similar reasoning, a variation of coal below the required amount can be shown to produce a reduction in the draft at the stack. A variation of five per cent. may cause a change in temperature at the base of the stack of over 200 degrees which is enough to change the draft very noticeably.

When the kilns operate with mechanical draft, all these imperfections are covered up almost completely, as the irregularities in fuel fed may affect the temperatures at the waste-heat chambers but will not affect the weights of the gases, and consequently will not affect the draft that the fan can produce. In other words, slight variations in the fuel fed to the kilns with mechanical draft will not be noticeable, while with a stack draft they would be very conspicuous.

The present coal feeders used for powdered-fuel power-plant practice are very elaborate and, so far, they have not found their way into the kiln room. To-day, two or three plants may be equipped with such types of feeders and it is expected that this movement eventually will reach into every kiln room of the country, and such a measure will be very beneficial. The reason this has not previously taken place is the cost. Sooner or later, this cost will demonstrate its economic possibilities and show that investments of this kind will be warranted.

It has been our experience that all our waste-heat plants in the cement industry have reduced the amount of coal fired per barrel of

cement. This means, not that we have actually burned a barrel of cement with less heat, but that we have made the available coal more efficient, and, therefore, less coal has been necessary to produce a barrel of cement.

Several cement plants have reported an increase in the amount of coal burned per barrel after the waste-heat plant has been installed. This has been due to two causes:

1. The tendency of the operators is to overlook the matter of controlling the coal feeders so as to preserve perfect conditions of combustion—they vary the coal feeders without ever attempting to vary, at the same time and in the same direction, the draft produced by the fans.

2. There is a tendency to-day to burn clinker at a higher temperature, producing a harder clinker and, of course, this requires more heat and consequently more coal per barrel.

With regard to low temperature, it has been said that low temperatures will not pay for generating power because it would be difficult to recover enough heat to raise the required electrical load. It is true that with low gas temperatures, a small percentage of heat can be available with present boiler practice, and the lower the temperatures the less steam can be recovered. It has, however, been proved that dry plants will always have high temperatures and wet plants will have a tendency to have low temperatures. The low-temperature wet plant, however, has a greater gas weight, due to higher coal consumption and the moisture in the slurry, and thus the savings effected are practically the same whether the wet or the dry process is used —that is, the amount of steam recovered per barrel has been the same in both cases.

A cement plant has a definite power load to develop and, if the low temperatures of the gases do not permit the recovery of a sufficient amount of steam to generate such power, it means that the turbine should be of higher efficiency.

Water has been the standard medium for transferring the energy from the boiler into the turbo-generator, and it is the cheapest, safest, medium available. However, it has certain characteristics that are prompting the idea of looking around for improvements. The percentage of heat converted to useful work in a steam-turbine is very

small, due to the great latent heat that has to be dissipated in the condenser of the turbine, so, putting it in plain words, we are subtracting a very high percentage of the heat from the gases and a very small part of this heat is transformed into electrical energy. In the case of the low-temperature, waste-heat plant the percentage of heat taken out of the gases and transformed into electrical energy is still smaller as most of it is wasted in the circulating water of the condenser. These facts suggest the possibility of using other media than water to convey the heat from the boiler to the turbine.

The present practice of refrigeration has brought about a study of many media such as methyl chlorid, ethyl chlorid, propane, and butane. Some of these can be evaporated at a very low temperature and at very high pressure. They do not decompose unless they are heated to an extremely high temperature and they liquefy at moderate pressures under the action of the available temperatures of circulating water; so that it is possible, with low-temperature gas, to generate extreme pressures with some new medium and have this medium highly superheated and so transfer the heat from the gases into the turbine. The latent heat of evaporation of some of these media ranges from 150 to 180 B.t.u. per pound, as compared with water that evaporates from 900 to 1000 B.t.u. per pound, depending upon the pressure at which the change of state takes place.

It is possible that some developments along this line may take place in the near future and it is rather discouraging to think that such developments will take an extreme effort on the part of the engineer in order to convince the financier of their prospective value.

Something has been said about boiler ratings. It is true that waste-heat boiler plants operate at a very low rating. They have to do it, especially when the temperatures of the gases are low. We have a number of plants that operate at anywhere from 120 to 125 per cent. of rating during long operating periods and this rating covers wet plants as well as dry plants. The higher the gas velocities throughout the boiler, the more gases the boiler will handle and the more heat will be extracted from the gases, and that is the secret of the heat-recovery problem. If the fans are large enough to overload the boilers with gases, larger rating will be produced. However, we have limited the size of the fans to a certain point so that no further crowding of the gases would be obtained, as otherwise trouble may

develop or inefficient operation may result. In cases where the temperature of the gases entering the boiler is extremely high, the gases may be loaded with hard-burnt particles of clinker which combined with high gas velocities will have a tendency to erode the boiler parts.

With regard to burning auxiliary fuel, this is a very dangerous problem as a mixture of extremely hot gases, loaded with dust from the combustion of extra fuel, may produce an undesirable mixture which will fuse the dust. When once this condition occurs, the chambers are no longer suitable for operation.

Auxiliary fuel may be desired in the case of deficient power for the plant load. If the deficiency of power is very slight it is best to rearrange the load, cutting in and out the motors at convenient periods so as to take care of the load, thus distributing the available steam in the best possible manner as it is generated. This will show, in time, a schedule of operation throughout the plant that most likely will eliminate the possibility of small additional power.

Some of our customers have carried wonderful records. In one instance for a period of two years, not a pound of coal was burned under auxiliary boilers and not a pound of pressure was lost during the same period of time. In fact, these particular customers ripped out all of their separately fired boilers and put new turbines in their place. The method of starting this plant when thoroughly cooled down is interesting. The boilers at this plant are baffled four passes and there is a chamber underneath the second and third passes. They have many boilers so they have equipped one or two of their boilers in such a way that grates can be installed underneath this chamber, below the second and third passes, and over these grates, coal can be burned by hand. This is carried on until enough steam pressure is developed to get one of the turbines turning over and generating sufficient power to start one or two kilns. When the kilns start, other waste-heat boilers will soon get warmed up and up to working pressure and, once this is established, the first boiler that had the hand-fired grates can be shut down, the grates taken out, the doors sealed, and this boiler made ready for straight waste-heat operation.

We also have a customer who at one time started to burn natural gas in the main flue at the same time that this flue was used to convey the waste gases from the kiln to the boiler. It is unnecessary to state that the additional power he obtained without trouble was very slight,

for as soon as he fired the burners to such a point that the increased power was noticeable the temperatures were so great that the dust immediately began to fuse and a shut-down was necessary.

For the case where a plant needs considerable additional power, we have developed what we call the precooling boiler. The scheme under which it operates is that the additional fuel is burned inside of an independent furnace and then cooled through this precooling boiler to the temperature prevailing in the gases coming from the kilns so that at this temperature the gases from the precooling boiler will mix with the gases from the kilns and then finally become cooled through the waste-heat boilers. To accomplish this requires a very small amount of heating surface and therefore a boiler of this sort will operate at extremely high ratings—possibly 600 per cent. or more. With this scheme, the coal can be burned under the very best conditions and the gases from this coal precooled to the temperature of the gases from the kilns. The remaining heat can be extracted by means of waste-heat boilers which are equipped with economizers, so that the economy of this scheme is as high as any central-station power-plant of to-day, which means that any auxiliary coal burned in this fashion can be so arranged that it will burn to a possible 85 to 90 per cent. efficiency.

The precooling boiler will not be practical when very small amounts of extra steam are required, as the investment will be so high that it would be cheaper to purchase a slight amount of power should it be necessary.

Something has been said with regard to fans driven by steam-turbines. The original scheme of a waste-heat boiler plant was to produce the highest possible economy and, in order to obtain this, we conceived the idea of driving the waste-heat fans by means of steam-turbines as it showed that the turbine was going to consume enough steam so that its exhaust, at atmospheric pressure, could be used to heat the feed-water to boiling point so that this could be fed to the economizers. Unfortunately, the steam-turbine has the peculiarity of increasing its water-rate if its speed is reduced. The steam-turbines could not be held at high constant speeds as the variation in fan speed was required. That immediately brought about the high water-rate of the turbine which, in turn, produced too much exhaust steam for the required heating of feed-water. Furthermore, the speed of

the turbine is dependent upon the pressure, and, if the steam pressure should happen to drop, the fan speed would also drop, which has a tendency to aggravate the conditions. We realized this point several years ago and several of our different plants that had been originally equipped with steam-turbines to drive the fans, have been changed to motor-driven fans, increasing the efficiency of the plant and obviating the difficulty of the changes in the steam pressure.

To design a fan for waste-heat purposes, a small wheel and a high speed can do the same work as a large wheel at low speed; but only one particular speed and one particular diameter will render the highest efficiency, and this is the point at which fans should be designed. It is very unfortunate that the larger the fan for the same work at a low speed the greater the cost, because the fan becomes larger and because the motor to drive it becomes more expensive due to the low speed. However, in our experience we have found out that hardly any criticism has ever been made with our fan installations and they all have turned out to be quite successful because we have tried to keep our fans at the maximum practical efficiency.

The fan is the heart of the plant and if the fan stops, the whole plant is down. Bearing this in mind, we developed what we call the fan flue. The fan flue is a flue into which all the boilers are connected and into which all the fans are connected and it will thus enable any of the fans, at any time, to be shut down or put in service without interfering with the general plant operation. The characteristics of fans are such that when parallel operation of this sort is necessary, the fans should be designed so that they will not hunt the load, which means that they should operate far away from the pick point of the characteristic curve and, of course, on the side of maximum efficiency. With this scheme, fewer fans of larger size can be put into use with a saving in initial cost and with increased efficiency. Our plants of this sort have operated and are operating to-day with excellent results.

J. R. Mason:* I am very much interested in Mr. Smith's statement that first consideration must be given to continuity of service and flexibility, and that a 24-hour delay may wipe out the economies of an entire month. I agree that continuity of service is very important, and believe that the inclination at the present time is to

*District Sales Manager, Wickes Boiler Co., Pittsburgh.

install boilers that will have a lower draft loss and a lower velocity of gas, which will not be so heavily dust laden. Not so much dust will be carried over to pass through the fan and, the velocity being lower, the dust is not so abrasive. The high velocity of gases passing through any boiler increases the dust-carrying capacity of a stream of gas to a tremendous extent. There is no argument, of course, against high velocity for heat absorption; but, as Mr. Smith says, first consideration must be given to continuity of service.

I believe that waste-heat boilers ought to be worked out so that nearly all parts of the heating surface could be reached by mechanical soot blowers in order to prevent the opening of large doors to clean the heating surface by hand. This would prevent admitting a large amount of cold air while the cleaning process is going on.

Mr. Smith's paper shows a very close study of waste-heat questions, and a desire to meet existing conditions and overcome the difficulties in operation.

F. Falla: By way of answer to Mr. Mason's question, it must be remembered that the elimination of the cause is the elimination of the effect, but the elimination of the effect does not remove the cause.

The deposition on the boiler tubes is traceable entirely to improper combustion in the kilns or furnaces. The hydrocarbons produced by incomplete combustion have a very high boiling-point or liquefying point and that causes them to condense on the surface of the boiler tubes. Once this condensation starts, it grows much worse, because the condensation forms incrustations that block the passes, further reducing the draft for the furnaces and further increasing the amount of hydrocarbons present in the gases. From this it can be seen that the elimination of the trouble lies in correction of the combustion in the kilns or the furnaces so that they will burn the fuel completely before it enters the boiler setting.

In the paper industries, they burn the "black liquor" which is a very poor fuel. There is no furnace to-day that can burn this fuel completely, and that part of the fuel that does not burn in the furnace condenses in the boiler tubes and causes trouble. The cure for this trouble is to go to the manufacturers and work hand in hand helping

with the combustion problems so that the gases are thoroughly burned before they enter the boiler setting.

Our experience is such that we have personally run kilns for days, checking the gas analysis and the drafts to a point which thoroughly demonstrates the completeness of the combustion before the gases enter the boilers and during that operation no troubles were experienced, no matter what the temperatures were.

All we have to do to solve this problem, is to investigate the combustion problems and teach the burners or furnace operators to burn properly, and this is the way to eliminate the problem of boiler incrustation.

G. E. Dignan, *Chairman*:* Mr. Bradford brought up an interesting point when he mentioned the possibilities of power interchange. This is something which should be very carefully considered in the development of industrial power plants, both waste heat and direct fired. Mr. Dreyfus of the West Penn Power Company has been giving considerable thought to this subject. I wonder whether Mr. Dreyfus would be willing to say something about power interchange.

E. D. Dreyfus:† Mr. Smith has made a very instructive contribution to this meeting, and I shall attempt to give some additional viewpoints for consideration. There are usually two sides to every proposition or problem, and in our position as wholesalers of power we have been brought into contact with a number of cases where cement companies were considering whether it was best to install a waste-heat plant or to buy power. Power is now being purchased in all cases but one, where short kilns operating with high exit temperatures were in use and where dust abatement was also a problem.

Mr. Smith in his paper stated the possibility of generating power for 4½ or 5½ mills per kilowatt-hour when virtually operating at full capacity continuously. I believe that may be possible under ideal conditions, but, of course, ideal conditions do not always obtain. It is also necessary to take into account the fact that cement plants do not operate constantly, and we have to consider the normal interruptions

*Chief Engineer, Rust Engineering Co., Pittsburgh.
†Research Engineer, West Penn Power Co., Pittsburgh.

and fluctuations in operation. Furthermore, the cement industry has for several years been enjoying a rising tide of business, which probably may continue for a time; but, as the country becomes well supplied with good roads, and building work is well caught up, the consquence may be the dividing of a relatively small volume of business among the existing producing plants, resulting in a material lowering of their load-factor.

In this connection, some statistics published by the Portland Cement Association, as reproduced in Fig. 1, are enlightening. These figures show the growth in consumption and in capacity for production of Portland cement in the United States. It remains for the cement producers to interpret the significance of the widening gap between plant capacity and demand.

When you study installations of the kind discussed in Mr. Smith's paper, which require flexibility and reliability together with the necessity of being designed to meet definite combinations of conditions, you find they entail a higher investment than is evident at first. In some locations the conditions are more favorable than in others. In one or two instances which I recall, the water-supply presented a problem. When you finally embrace all the different factors involved you will obtain a result which, in all probability, will depart considerably from the favorable power cost quoted by Mr. Smith. Then, again, you will find that preparations for purchased power may be made much more readily and at less cost for changing load conditions. The flexibility factor on all items is preponderantly in favor of purchased power.

While waste-heat boilers have been installed in connection with both the wet and the dry process, the latter unquestionably offers the greater opportunity, particularly if short kilns are in use. The tendency within recent years in the installation of new cement plants has been definitely towards the wet process, and it is to be noted that most plants are now buying their power. A previous speaker has noted the fact that a larger volume of waste gas is available where the wet process is used. The exit temperature is lower, however, and therefore the available heat may not be appreciably different, as the following comparison indicates:

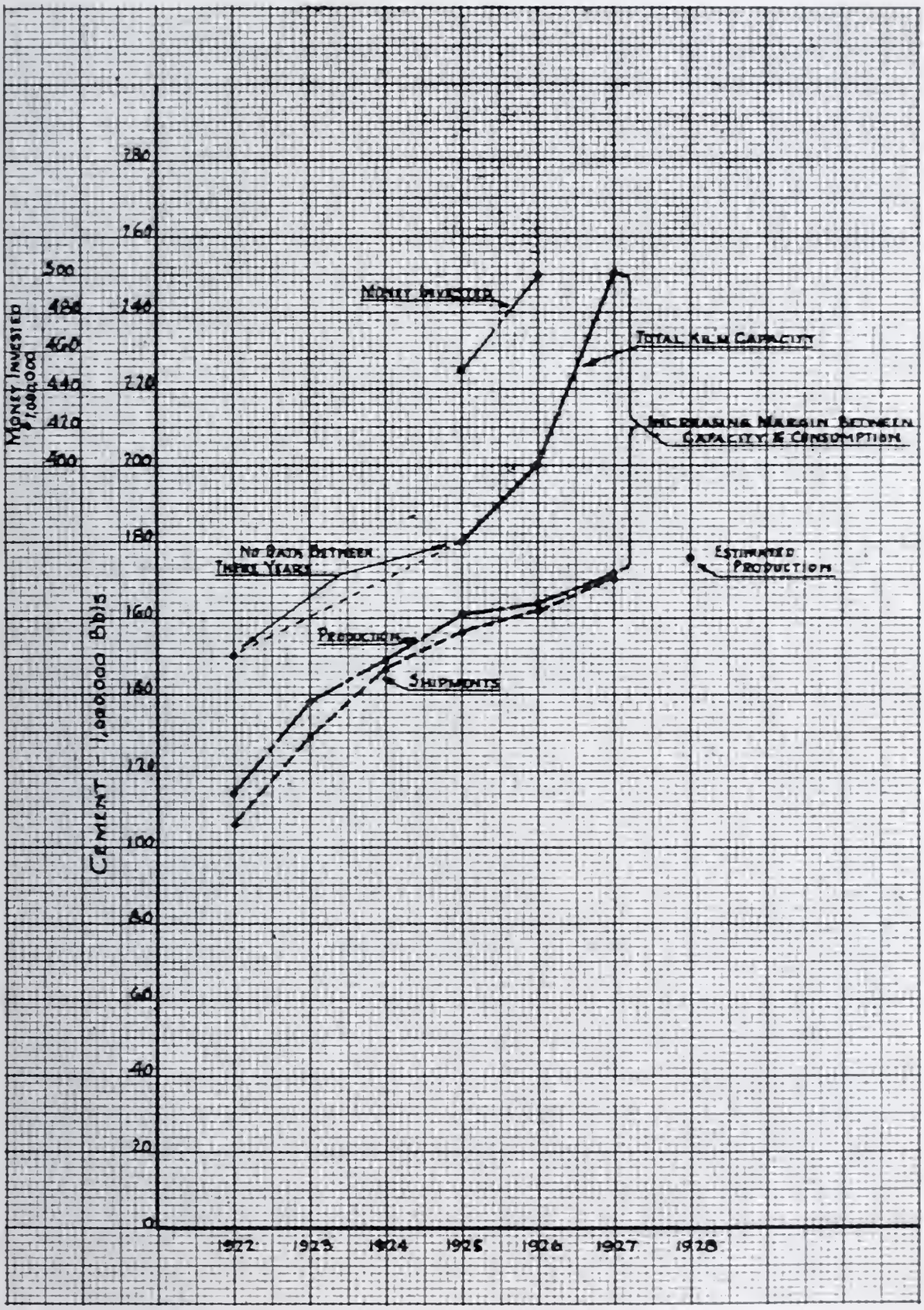

Fig. 1. Production and Consumption of Cement.

	Dry process	Wet process
B.t.u. in fuel to kiln per barrel of clinker.....	1,121,893	1,568,000
Pounds of coal per barrel of clinker.....	87.6	120
Pounds of gas per barrel of clinker.....	1551	1810
Temperature leaving the kiln, degrees F.....	1250	1040
Specific heat of gas above 200 degrees F.....	0.2810	0.2840
Available B.t.u. in exhaust gases.....	458,000	432,000

With the usual run of conditions, there will be more available heat per barrel of clinker with the dry process.

It is also to be borne in mind that cement plants are ordinarily operated in conjunction with the mines or quarries providing the raw material. Sometimes stone is produced for cement manufacture only, and in other instances additional stone is mined for the general market. An even balance of available heat and power needs is rather infrequent. Either power must be wasted, which causes a high investment cost per unit of useful or used power; or, if a deficiency exists, auxiliary power of some sort must be arranged for, and combining different sources of power often creates more costly operation.

There is one case of which I have personal knowledge, where extensive refinement was introduced in the installation of a waste-heat plant. While reliability and low cost of operation were no doubt obtained, the high cost of the installation unquestionably created an unfavorable economic condition, and, in view of low load-factor possibilities, a more simple and less expensive plant (or purchased power if transmission lines were near) would have been preferable.

One of the difficulties in weighing conditions is the lack of complete operating data. The maintenance costs which are often referred to usually apply to waste-heat boiler plants which have been installed rather recently, and we know it takes some time for an installation to reach its normal stage of maintenance requirements. It does not do so when new, of course. Moreover, when we consider the matter of fixed charges, the disposition of a good many is to use low rates. Obsolescence is a factor, but it is often neglected. We know that as time goes on replacements must be made in bulk. The funds for this purpose are frequently taken from renewals and replacements or depeciation reserves, whatever term may be used. There is danger of

this fact being lost sight of when we prepare our original figures as to whether or not an installation of this or that kind should be made.

The advantage of an interchange between the central station and the industrial plant will in every case depend on local load conditions. Ordinarily, unless the industry can contribute a substantial amount of capacity in relation to the needs of the central station, and unless it is so located that it may unfailingly and promptly respond to load dispatching orders, it can not be counted upon to influence the latter's fixed charges materially. Some benefit may be realized through an interconnection, but as a general proposition the total savings to the central-station system will be but little more than its incremental fuel costs. The explanation is that the central station builds up its generating capacity in large blocks or additions to obtain a high efficiency in both installation and operating costs, and consequently carries a certain amount of marginal capacity in order to keep ahead of its growing load. Its building program would not, therefore, be altered by any power interchange unless the capacity which the local industry could make available constantly or upon call were of the same order of magnitude as the additions the power company is required to make from time to time.

It will be usually found that the central station is interested in any likely interchange situation and welcomes the opportunity to ascertain jointly the economic advantages for all interests. In all cases, the conditions should be thoroughly investigated with the cards laid on the table. Such a spirit of co-operation has prevailed in the cases to which I have alluded, and to date there has been no evidence of an economic blunder having been made. Manifestly, at the expiration of the contract period, the industry may revise its practice.

Power users often obtain a wrong notion as to what their costs are, and I think it devolves more and more upon the engineer to give serious consideration to these economic questions, as he has so creditably done with the mechanical problems.

N. D. Moeller:* Even if we could purchase power at the cost of production, I think it is still our duty to posterity to conserve our natural resources by utilization of waste heat.

*Mechanical Engineer, Koppers Co., Pittsburgh.

W. B. Skinkle:* Mr. Dreyfus has made some very timely and important remarks in the discussion of Mr. Smith's paper, particularly when he discusses the value of interchange between the central station and the industrial plants lying within their territory. The local conditions surrounding each and every problem of this type must of necessity exert almost the predominating influence on the economics of each situation. I do not believe this thought can be too strongly emphasized. I have made a great many detailed surveys of industrial power developments in the past 10 years and I have found that peculiarities in the local conditions have controlled almost every one of them. I have handled several negotiations for the interchange of power between industrial concerns and public utilities. Some have been successful and others have failed. In all cases, the local conditions were the controlling factor. At one place the industrial concern showed an increment cost of only 0.6 of one mill per kilowatt-hour for energy, and would have been willing to sell power at almost any figure greater than that, but the negotiations failed for the reason that at the place where the energy could have been delivered the power company was already thoroughly protected, and further, owing to the peculiar distribution of load and transmission facilities, power delivered at this point was of almost no value to the power company.

At another concern located less than two hundred miles from the place just mentioned, an increment cost of 2½ mills per kilowatt-hour was very interesting to the power company. The particular load conditions controlling this case lay in the fact that the plant was located near the end of a long transmission line and the power company found it necessary to operate a power-house and run a good-sized turbo-generator at no load just for the purpose of power-factor correction and voltage regulation. The interchange agreement with the industrial concern enabled the power company to shut down and abandon its relatively small and uneconomical station and arrange to secure the voltage and power-factor regulation from the industrial concern.

I could go on and enumerate instances almost indefinitely, but I think these two serve to illustrate why interchange agreements that apparently look good at first glance often amount to nothing, and how important the local conditions surrounding each problem really are.

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HIGH-SPEED GEARS*

By E. N. Twogood†

It is one thing to choose a subject and still another to define it so everybody can think in the same terms. High-speed gears, as the trade thinks of them to-day, are those gears which operate at high speeds or velocities. The American Gear Manufacturers' Association has recently divided the herring-bone gear into two classes. First, those which operate at a pitch-line velocity below 4000 feet per minute, to be known as low-speed or industrial gears; and second, those which operate at greater velocity to be known as high-speed gears. The latter definition to some extent explains the subject of this paper.

The purpose of a high-speed gear, or in fact any gear, is to permit the driving and driven members of a complete set in which the gear is a part to operate at their best and most economical speeds.

Most all apparatus to-day requires some type or form of gear. The ordinary lathe has its train of driving and back gears. The high-speed drill must be speeded up by gears. The low-speed drill must be driven through reduction gears for materials which require slow cutting. Motors must be reduced in speed so as to drive rolling-mills, and operate conveyors and belts. Again motors must be speeded up by speed-increasing gears for driving compressors, fans, and blowers. Turbines are reduced in speed for driving generators, pumps, line-shafts, etc., and speeded up for the still higher centrifugal compressor speeds. The automobile has its differential transmission and timing gears and even "time" must be ticked off and recorded by gears. In fact, gears are the levers of the universe, some transmitting power and some uniform motion only.

Before entering into details of the high-speed gear, it might be of interest to know something of the history and origin of gears. Both Egypt and Babylon are given credit for the origin of toothed wheels. Pictures made about 700 B. C. showed pulleys and levers but not toothed wheels. Aristotle mentions the fact that two circles rubbing on each other would rotate in opposite directions. It is evident that the Greeks knew of at least friction gears. About 200 B. C., a toothed-wheel train was devised for measuring the distance a vessel travels.

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A paddle-wheel was rotated by the passing of a vessel through the water, and this rotation was transmitted through a toothed-wheel train which rotated a box containing stones. Each time the box rotated a stone was dropped out and the distance the vessel travelled was measured in stones. This gear-train was composed of wheels having pins in the periphery. The first mention of the involute curve was by Christian Huygens in the latter half of the seventeenth century. Epicycloids were discussed in a theoretical way by Desargnes in 1674, but the best insight into ordinary usage in gearing is found in the works of Mandey and Moxon in 1696. One of the first cutting machines was made in 1771 and was really a hand tool for cutting wooden teeth. All the gears up to the middle of the nineteenth century were either wood or cast and were of the cycloidal type. Since that time, the involute has completely replaced the cycloidal, as slight imperfections in the involute and slight variations in center distances do not have as serious effect on the single involute form as on the cycloidal. The first known hobbing machine was made in 1835.

High-speed gears can be operated as either speed increasing or speed decreasing and our experience shows that either can be accomplished with good operation and efficiency.

The design of high-speed gears, as of all gears which transmit power, must be of proper proportions to transmit the power required in an efficient and dependable manner. The first thing to consider in the design of a high-speed gear unit is the pinion, it being the weaker member of the two rotating parts, and, in order to keep the pinion rugged and yet have the pinion as small as possible, so as to reduce the velocity to a minimum, the pinion is nearly always made integral with the shaft. The shaft must of course be of sufficient diameter to carry the load at the required speeds, and the pinion of course can not be any smaller and usually is larger due to manufacturing requirements. Given, therefore, the load, the speed, and the minimum diameter, we may choose for the first trial a pitch diameter a little greater than the minimum shaft size from which the number and size of teeth can be chosen, and the pitch-line velocity in feet per minute calculated at the given speed. The total driving pressure, then, at the pitch diameter is horse-power times 33,000 divided by pitch-line velocity.

The carrying capacity of the tooth chosen is determined from experience for this particular speed and application, and this allowable

tooth pressure per inch of active face divided into the total driving pressure gives the required active face. In this way we determine the dimensions of the trial pinion, and it is next in order to see if a pinion of these dimensions is of sufficient rigidity to maintain a good tooth contact for its entire length of face. This is checked in two ways; first, for bending and, second, for torsion.

The general outline of a pinion and its integral shaft is shown in Fig. 1, sketch *a*. This pinion consists of two helixes. Helix 1 is called right hand because the teeth are cut similar to a right-hand

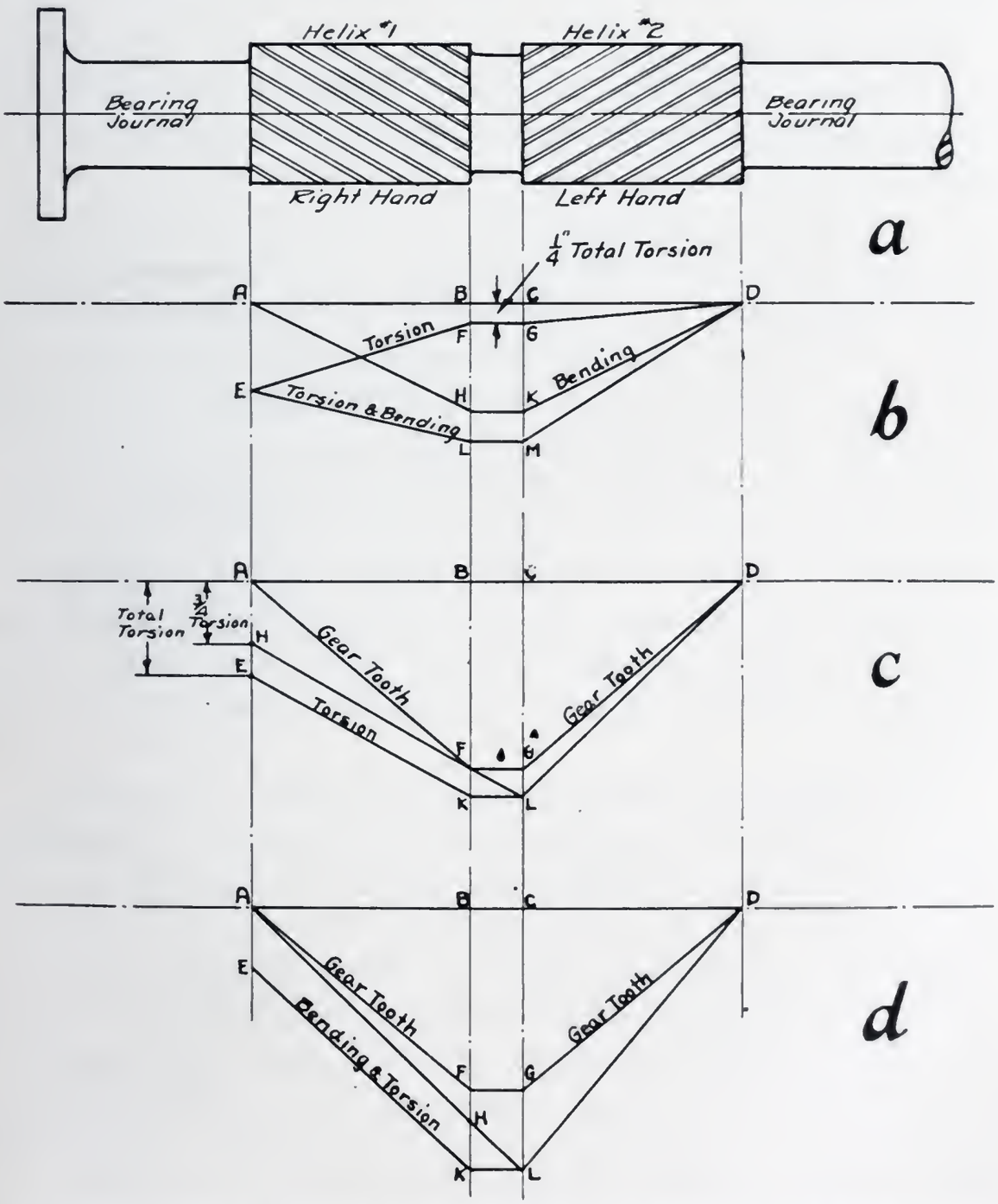

Fig. 1. Pinion and Shaft, Showing Effects of Bending and Torsion.

thread, and helix 2 is called left hand because the teeth are cut similar to a left-hand thread.

As to the bending, we are interested in the difference between the deflection of the pinion at the center and at its ends, as it is this deflection which affects the contact of the pinion and gear teeth. The deflection diagram for bending is shown in Fig. 1, sketch *b,* line AH and KD, the deflection at the apex of each helix being BH and CK. If this deflection is too great, it will cause a greater part of the load to be carried on the base of each helix, thus overloading that portion of the tooth.

The bending alone, however, does not determine the effective tooth contact, as the torsional twist also plays its part although perhaps not to as great a degree when only a two-bearing pinion is used, but greater when a three-bearing pinion is considered.

The shaft and pinion are subject to torsional twist, due to the load carried, the load in this case being the driving pressure on the teeth. If the pinion is properly designed, this load is practically uniform over the entire face and therefore that part of the pinion (or helix) next to the driving end must carry its own load, plus the load of the other helix. The greatest torsional stress in the shaft is, therefore, at the base of the helix next to the driving end and this tends to cause the teeth at this end to lag by the amount of the torsional twist at the pitch diameter, and change the helical angle by that amount.

The torsion diagram is shown in Fig. 1, sketch *b,* line EF and GD, with a deflection of helix 2 at the apex of CG and at the base of helix 1 of AE, the deflection at CG being just ¼ of the total deflection.

The effect of the torsion on the tooth contact is shown in Fig. 1, sketch *c.* Consider the developed gear tooth AF and GD, and draw the deflected developed pinion tooth EK and LD showing the total torsional twist of AE at the base of helix 1, and ¼ of total torsional twist GL at apex of helix 2. The pinion and gear teeth would theoretically be in contact at D only, but, as the helixes are so made that the axial pressure on each helix is equal to and opposite to the other, both helixes must be in contact at some point or one element will shift axially until they are. From Fig. 1, sketch *c,* you will note that the pinion tooth EK is not in contact with gear tooth AF at any point; therefore, the pinion will shift to the right until the pinion

tooth EK takes up the position HF and contacts with gear tooth at F. The effective tooth contact for torsion is therefore AH, or ¾ of the total twist at the base of helix 1, and GL or ¼ of the total twist at the apex of helix 2.

Having determined the separate effects on tooth contact of both bending and torsion, it will next be of interest to see what effect the combination of the two has on the tooth contact.

The bending diagram is shown in Fig. 1, sketch *b,* by AH and KD, and the torsional diagram by EF and GD. As these two deflections are approximately in the same direction, the two can be added as shown by EL and MD. The effect of this combination of bending and torsion is shown in Fig. 1, sketch *d,* where again we lay out the developed gear teeth, AF and GD, and place in contact therewith the developed pinion tooth EK and LD, when, under both a bending and torsional load, we get the deflection at AE equal to the total torsion and at FK and GL, the total bending plus ¼ of the torsion. As the gear and pinion teeth of helix 1 are not in contact, the pinion will shift to the right until E comes in contact at A; then the contact will be at A and D, and the teeth will be open GL or bending plus ¼ of the torsion at the apex of helix 2, and somewhat less at the apex of helix 1 as shown by FH. Where a two-bearing pinion is considered, therefore, the maximum effect of both bending and torsion on the tooth contacts is at the apex of helix 2 and is equal to the total bending plus ¼ of the total torsion, and our experience indicates that the sum of these two should not exceed 0.0008 inch, and we have placed in service high-speed gears that have operated satisfactorily for years under these conditions.

When a three-bearing pinion is used, the bending is reduced to nearly zero, and only the torsion is effective, and, as shown above, only ¾ of the total torsional twist need be considered, and our experience indicates that this deflection should also be held within 0.0008 inch in order to obtain the best results. An excessive deflection caused by either bending or torsion would cause the load to be carried on a part of the face only, increasing the load on the face that is in contact and eventually causing excessive wear of the tooth surface and fatigue of the material at the root of the tooth.

It is true that these conditions apply to low-speed gears as well, but they do not enter into the limiting features as much as in high-

speed work because in high-speed design it is necessary to keep diameters as small as possible so as to keep the velocities within good engineering and manufacturing limits.

Regarding velocities and speeds, a few years ago we considered 7500 feet per minute pitch-line velocity as about the maximum limit of good operation. To-day we have units in operation at nearly 15,000 pitch-line velocity and see no particular reason for stopping there. As to speed 3600 r.p.m. was considered high a few years ago, but now we are operating some turbine sets at 10,000 r.p.m., and have recently installed some centrifugal compressor sets, the compressors of which operate at nearly 30,000 r.p.m.

Having determined the proper pinion to use as outlined above, the diameter of the gear is, of course, determined by the ratio. That is, if a 5 to 1 ratio is required, then this gear must be 5 times the diameter of the pinion, and with these dimensions it is next in line to design a rigid casing to be able to obtain and maintain the center distances and line-up for proper tooth contact.

The determination of the proper tooth form is also a very important factor in the carrying capacity and life of the gear. Several years ago our Company ran a series of tests using pinions and gears of the same diameter and material, but varying the tooth proportions including the size, length, pressure, and helical angles. In order to obtain quick and comparative results the tooth load in all cases was made 3000 pounds per inch of face, and invariably the results indicated that the tooth which held up the best, from the standpoint of both strength and wear, was the combination of having the greatest number of teeth in the arc of action, or the greatest number of teeth in mesh at any time.

As the length of tooth and the pressure angle influence the arc of action more than any other feature, we came to the conclusion that the longer tooth and the smaller pressure angle would give us the best results, and since that time our tests have been backed up by operating results. It must be understood, however, that the length of the tooth can not be increased or the pressure angle decreased to the point of causing interference, as this would decrease the arc of action and weaken the tooth, and there might also be trouble with lubrication.

No matter how good the tooth proportions are, or how rugged the design, a gear is no better than its lubrication system. For long

life and good operation, an oil film must be continuously kept on the gear teeth, and the bearings must be kept well oiled or excessive bearing wear will cause poor tooth contact and noisy operation. In work with high-speed gears, the teeth must not run in oil as this would cause excessive heating due to the high rotation loss of the gear in the oil and the efficiency of the gears would be lowered.

It is difficult to keep oil on the teeth of high-speed gears due to the centrifugal force. It is, therefore, general practice to devise some method of putting the oil on the teeth just before they enter the mesh and, in this way, the gear tooth carries the oil to the bottom of the working face of the pinion tooth and the pinion tooth carries the oil to the bottom of the tooth surface of the gear and both surfaces are well lubricated. As stated, there are many methods of supplying this oil to the mesh and we find one very good way is by the spoon oil nozzle which directs a thin wide film into the mesh with the minimum quantity of oil required. In this way, very good lubrication is obtained with about one half gallon of oil a minute for each inch of gear face. The bearings, of course, require the proper amount of oil to carry away the heat generated. Depending upon the size of journals and speeds, this requirement is from 0.05 to 0.08 gallon per minute per square inch of projected area. For successful operation, our experience shows that for high-speed gears both gear mesh and bearings should be force lubricated, the oil being furnished either by a pump driven from one of the gear shafts or from a pump driven by the driving or driven elements. The manufacture of high-speed gears is a specialty in itself with accuracy as its key-note.

To obtain proper contact, the casing must be bored so that the pinion and gear shafts are parallel and at the correct center distance. The tolerances must be kept within a half thousandth. The rotating parts must be hobbed so that the helical angles of both gear and pinion will cause the teeth to come into contact the full length of the face. The teeth must be cut so that there is bearing from the top of the face of the tooth to the bottom of the tooth, and must be spaced uniformly so as to avoid acceleration or deceleration of one member relative to the other, thus causing noise and excessive wear. With uneven spacing, the inertia of the rotating parts at such high speed due to the acceleration and deceleration, causes excessive loads on the teeth, and results in noise, fatigue, and breakage.

To cut high-speed gears having uniform spacing, the hobbing machine must be designed to be both rigid and accurate—rigid to carry the load of both the weight of the gear and the cutting strain without deflection, and accurate in order to generate the proper angle and tooth spacing. The proper tooth spacing is one of the hardest problems of high-speed gear cutting. As a whole, it is the key to elimination of the greater part of the noise of gears. Up to a few years ago, it was not known how accurate this spacing had to be in order to produce a noiseless gear. We knew it was possible to manufacture a gear which would operate quietly, but did not have instruments to measure its degree of accuracy within the limits of quiet operation. It was, therefore, necessary to cut a gear, check it the best we could, and operate it. If quiet, we considered we were lucky, and if noisy, we knew something was the matter but just where to put our fingers on it was more or less good judgment and a "cut and try" method.

Periodic inspections of the hobbing machine are necessary to insure that it is being maintained in good condition. These inspections in order to fulfil their purpose have to be very thorough and accurate and the time taken by them becomes an important item. The hobbing machine is as good as the work it produces and a ready and reliable method for checking the spacing of the teeth as cut by it would give a means of verifying its good condition or, as the case may be, a starting point for the diagnosing of its possible ailment. This would do away with the necessity of taking it out of service for recurring inspections and, when an overhauling proves to be due, offer a guide pointing to the particular group of the gearing in the hobbing machine that may be the root of the trouble. Such a method was developed within the organization, its originator, Mr. F. L. Pearson, receiving a Coffin Award during the year 1927 in recognition of its merit.

This method checks the uniformity of the spaces of a helical or spur-gear. The gear may be supported in a horizontal position on its journal in vee blocks and a short steel pin be placed between the adjacent teeth approximately vertically above the axial center-line of the gear. The steel pins should be straight and exactly round in cross-section and have a diameter of a size to make the pins contact with the teeth approximately at the pitch-line. A knife-edge is established in a position parallel with the axial center-line near to the gear and a wide straight-edge placed so as to have as its only supports the

knife-edge and the steel pin, leaving it free to pivot within a reasonable arc about the knife-edge. The location of the knife-edge may further be chosen to bring the straight-edge into a horizontal position so as to accommodate a straight-edge of suitable length. An indicator graduated in ten-thousandths of an inch is placed over the straight-edge in a plane perpendicular to it and containing the axis of the gear so as to register the position of the straight-edge. By means of this indicator, any change in the distance of the straight-edge from the axis of the gear can be observed. The gear is now rotated slowly back and forth so as to make the space in which the pin has been placed, pass through the plane perpendicular to it and containing the axis of the gear, and a record is made of the reading on the indicator corresponding to the position of the straight-edge farthest away from the axis of the gear as it is being brought about the knife-edge. The indicator may suitably be adjusted to show zero at this reading. The pin is then placed in each of the other tooth spaces and readings similarly recorded for each one at the highest position of the straight-edge.

The differences showing up in the position of the straight-edge as the pin is placed in the consecutive tooth spaces is from 1.37 to 1.92 times existing errors in the spaces for inclinations of the tooth profile or 20 to 14½ degrees, respectively, thus further increasing the sensitiveness of the method. The plotting of these readings in rectangular co-ordinates, would give a straight line for a gear having no errors in the spacing and being perfectly concentric in the cutting. A curve following the general shape of a sine-curve, indicates eccentricity. Abrupt changes in the curve would show irregularity in the spacing, and the recurrence of these changes or their periods in relation to one revolution of the gear-blank, may be used to identify the member in the hobbing machine causing the irregular spacing, this member to have the same period with respect to the revolutions of the blank. Such a curve will show very clearly the actual conditions of the gear, as it gives directly the error from tooth to tooth as well as the cumulative error, doing away with any estimating of the accuracy of the spacing, by averaging the cumulative error over the number of teeth, a procedure which, as may be readily realized, does not often give a true record. Sets of readings using a common zero setting for the indicator and taken in different planes along the helix of the gear, give, when plotted in polar co-ordinates, an accurate and readily visu-

alized representation of the spacing, concentricity, and uniformity of thickness of the teeth for the helix of the member being checked.

This method of checking which, for ready reference, we may call the "pin-check" method, is also an accurate and convenient means of establishing the relative amount of wear on the teeth around the circumference of the pinion. This may particularly be of interest in the case of gear units which during their service have developed a case of rough operation which can not be corrected by attention to accuracy in the line-up of the gear members one to another and to the unit to which the gear is coupled, and where direct observation of the condition of the teeth does not show any cause for rough operation. When checks of this kind are made, the results are most clearly given by plotting the readings in polar co-ordinates. Fig. 2 shows a chart from a pin-check reading.

The time required to cut a large gear runs into weeks. The finish cut takes from one to two weeks of continuous cutting during which time the hobbing machine must run night and day without even a short shut-down. If, for any reason, a shut-down does occur, it is necessary to make another finish cut, so to avoid this we have installed battery sets which with automatic switches pick up the load if the power goes off, and thus guarantee continuous operation.

The accuracy of the hob is another very important feature in cutting accurate teeth and every hob must be checked by cutting templets which must pass a very rigid test for tooth shape before a hob is allowed to be put into production.

The cutting of teeth in high-speed helical gears must be rated as a class of work requiring very close accuracy, the errors that may be allowed in the spacing of the teeth, for instance, being of a magnitude of tenths of thousandths of an inch, and keeping within the low range of the digit. The high pitch-line velocities at which the gears are required to run, make this accuracy necessary in order that the gears may give quiet operation and have a satisfactory length of life.

In spite of the many precautions taken during the manufacture of a gear, it is best to operate all high-speed gears in test to insure the good operation required, and any gear so operated and passed satisfactorily can be made to operate in the same way when installed at our customer's plant. However, the foundation must be rigid, the casing must be bolted to the foundation without twisting or drawing

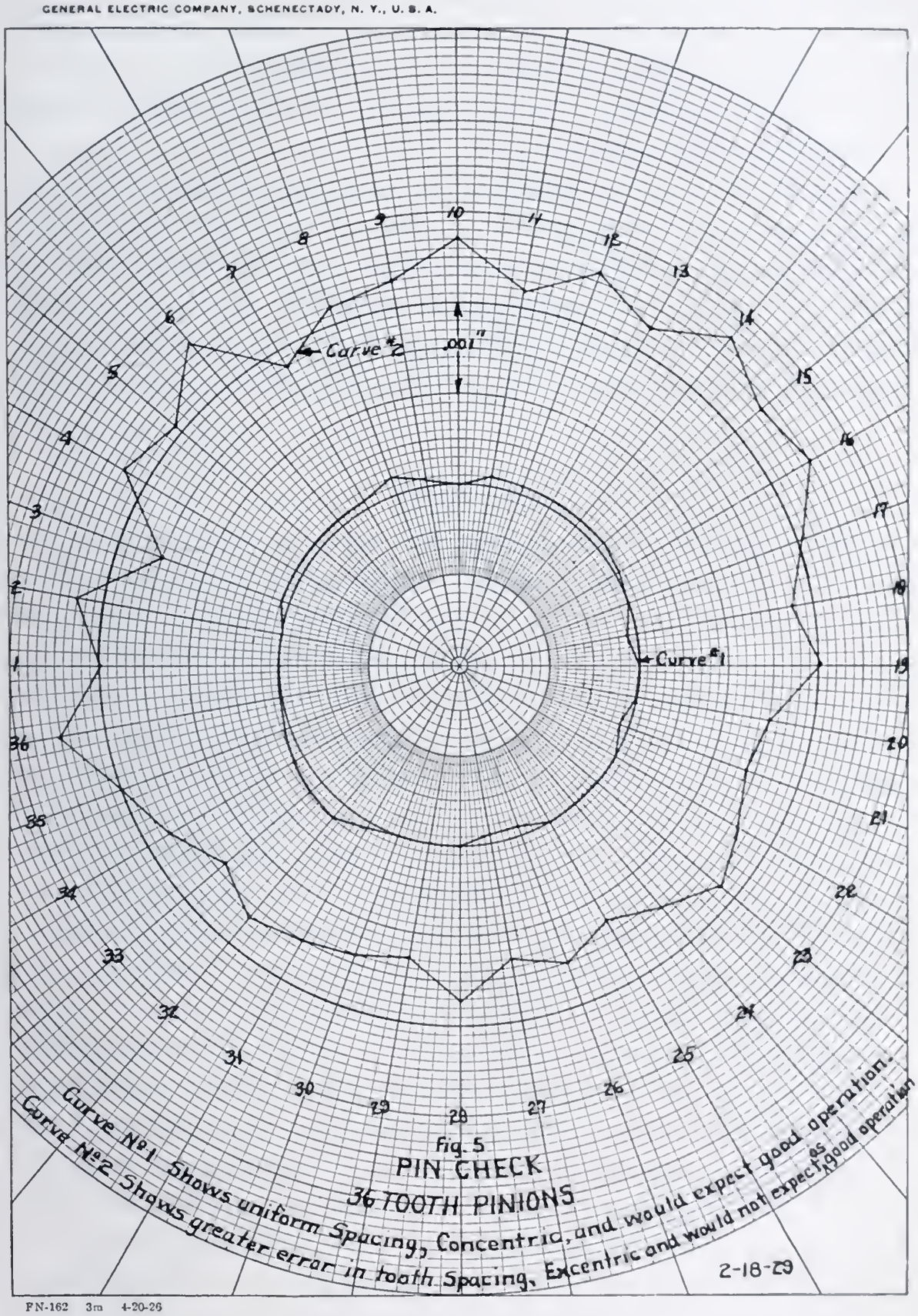

Fig. 2. Chart from "Pin-Check" Reading.

the casing out of line—which would cause the gear and pinion teeth to have poor contact—and last, but not least, the driving and driven elements must be connected and lined up to the pinion and gear shaft with a sufficient degree of accuracy so that the driving and driven elements do not interfere with the tooth contact or with the free trailing of the pinion and the gear.

The art of both the design and manufacture of high-speed gears has advanced very rapidly within the last few years and the demand for higher speed (due to both better efficiency and less cost) is growing year by year and it is very important that we manufacturers keep up with the demand by developing even better designs and more accurate methods of manufacturing quiet and long-life high-speed gears.

DISCUSSION

Percy Day:* I am sure we all feel very much indebted to Mr. Twogood for his paper. It is very interesting to me, and I have no doubt to all of you. He made the distinction between high-speed gears and commercial gears, laying the dividing line at 4000 feet a minute. I think this is true, without distinction, that the principles involved in cutting accurate high-speed gears are just as important as applied to all other gears, the difference being merely a matter of accuracy limits that are commercial for the purpose for which you wish to use the gears. In other words, while we might not need dividing wheels with an error of 0.003 inch in the circumference of a circle 157 inches in diameter, or to correct our lead screws to reduce the collective error to 0.0004 inch in 10 feet, we do need accurate dividing wheels and we do need accurate lead screws, and the degree of accuracy that is commercially practicable should always be applied.

The segregation of gears by arbitrary limits of pitch-line velocity hardly seems to me to be logical. The amount of shock, vibration and trouble which you may have with a badly cut set of gears is more a matter of angular than it is of circumferential velocity. In other words, if you take a pinion that is inaccurate and that is attached to large masses, for instance to the rotor of a turbine or to a large motor, it is from the rate of change of angular velocity that you get your bumps that cause the grief—not the absolute velocity in feet per

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minute, but the rate at which the angular velocity changes. That, it seems to me, is what produces the unexpected shocks and forces that every gear designer tries to avoid.

This matter of addendum and length of contact of teeth is a most desirable thing for high-speed gears. The Falk Corporation manufactures a line of high-speed gears, has made several millions of horse-power of this type, and has encountered the same problems. Everything Mr. Twogood says is broadly true. In fact, we are going farther than that. At the present time we are making high-speed gears with two-tooth integral contact, which is, in some cases, even longer than the Brown & Sharpe Manufacturing Company tooth. When you try to apply exactly the same principles to gears for rolling-mills, for instance, you have some practical limitations to face.

The high-speed turbine gear is essentially a precision product characterized by very minute limits of accuracy, clearance, and size of teeth. In other words, the teeth are small, the velocities are high and the number of teeth in the smallest pinion that you use in a turbine gear is relatively large. For instance, a few years ago it was more or less accepted by turbine gear designers that they would never build a pinion with less than 30 teeth. To-day the tendency is to increase that number rather than to diminish it. The tendency now is to use smaller pitches and to take advantage of the greater carrying capacity of teeth with a longer arc of contact to reduce the pitch and increase the number of teeth for the same pinion diameter. When we come to ordinary commercial applications that is not always possible. In fact, I doubt very much whether any rolling-mill engineer would accept the very fine, very small, very light teeth that are used on many thousands of horse-power of turbine drives, for application to the kind of load you get in a rolling-mill. Not many years ago the design of herring-bone gears for rolling-mills was very different from what it is to-day. I well remember designing a set of gears, about 1912, for a large engine-driven sheet mill. Those gears are working to-day at Farrell, at the Mercer works of the American Sheet and Tin Plate Company. Those gears were one diametrical pitch and have 27 inches face. Incidentally, they were as big as we could cut at that time on our largest hobbing machine. If we had been asked to make them any bigger we would have been out of luck. There was quite a storm of criticism when the order was placed for those gears.

The only example I know of a cut herring-bone gear in a sheet mill before that time was the gears at the Apollo works. I believe they are still working. Those were about twice as great in diameter, about twice as wide on the face, and were one-half diametrical pitch; that is, about 6¼ inches circular pitch. Everybody predicted disaster for those ridiculously fine gears put on a sheet mill at that time. Since that time, of course, there have been hundreds of gears built for all kinds of rolling-mill service on pitches from one diametrical pitch and smaller. Very few are larger, though there have been a few cases where we have been asked to build heavier pitches and have done so. However, it is true to-day and I think will be true always that commercial gears acceptable for heavy rolling-mill service and other duty of a similar nature will have larger pitches and fewer teeth in relation to the diameter of the pinion. Always, of course, you must be governed by the fact that the diameter of the gear is the same multiple of the diameter of the pinion as the gear ratio, and you begin your design by ascertaining the strength of the pinion shaft that is necessary, which gives some indication of the minimum diameter of pinion you can use. For economical reasons you try to design around that minimum diameter. You then find that you have a pinion which may have 15, 16, 17, or 20 teeth with pitch of proportions that are generally acceptable. Such pinions cut by the usual methods require some enlargement. If you had to cut these very long addendum teeth with a pressure angle of 14½ degrees you would have trouble with interference both in cutting and operating. If you attempted to use in your pinions the number of teeth that the high-speed turbine-gear manufacturers use all the time you would find it impossible because you would reach such small pitches that no one would accept them, and with pretty good reason.

Naturally, when you are designing gears for very fast running mills you build them with more attention to extreme accuracy and you automatically reduce the pitch of the teeth, but never to the extent that is normally practiced in the turbine-gear industry. You have to consider a lot of things, your bearing clearances, the shocks that apply to the gears, and the chances of shock driving the shafts slightly out of line and concentrating the load temporarily on parts of the face width and producing heavy stresses on portions of the teeth. The general tendency, of course, is to use lighter pitches, taking advantage

of more accurate workmanship not only in the gears themselves but in the bearings and housings that support the bearings, the rigidity of foundations, etc., so that you get the most practical compromise for the purpose in view.

There is another point about heavy-duty gears that is very important. Mr. Twogood very aptly described a system of lubrication by means of a spoon spray with oil. That is the universal practice with high-speed gearing. The interval of contact during which the pressure is transmitted from any one point on a pinion tooth to any corresponding point on a gear tooth is exceedingly brief. You are dealing with very high angular velocity and very small pitches. You can imagine a pinion with 60 teeth revolving at 10,000 r.p.m., or let us say 6000 because that is 100 revolutions per second. There are 10,000 tooth contacts every second and the duration of any actual contact between one tooth in a pinion and one tooth in a gear is very short. That being the case, you can use a lubricant of relatively low viscosity. Oil is an excellent lubricant for that kind of a gear; but as you go down in the scale, increasing your load per inch of face, as you do, of course, when designing gears for heavy rolling-mill service, the duration of contact becomes longer and longer. The necessity for maintaining a film of lubricant to hold the steel faces of gear and pinion apart, is just as great as it was in the case of the turbine gear but you can not do it successfully with light oils. You have to keep on increasing the viscosity. And there is another very valuable property of some lubricants which can not be expressed in terms of viscosity—that is adhesiveness; you have to increase this factor to a greater and greater degree as your duration of contact increases and your loads per inch of face become heavier.

That introduces the problem of separating the lubricants used on the teeth from those used on the bearings. Naturally these thick compounds that are usually adapted to rolling-mill gears are not very healthy for journals and bearings, and so you have to separate your bearing and gear lubricants. At the same time in the larger rolling-mill transmissions you have the problem of removing a good many surplus heat units from the bearings due to high journal velocities, and that problem is very similar to the problem of a turbine gear. If a bearing needs more cooling than can be obtained by natural means, the usual method is to circulate oil rapidly through the bearing and

cool it outside the unit just as is done in the turbine gear. The only difference is that the gear compartment of your rolling-mill unit has to contain, or should contain, a different lubricant, and consequently some additional complication of separation between bearing compartments and gear compartments is necessary.

There is an intermediate class of unit where the velocities are fairly high and the loads are not unreasonably heavy, the class of unit that is used to drive the lighter rolling-mills, such as rod-mills, bar-mills, and mills that require moderate horse-power at relatively high speeds. We have been developing the idea of simplifying the lubrication of such units, and the choice lies between lighter compounds, which can be used under some conditions as bearing lubricants, and the heavier oils which, of course, are all right in the bearings and give better protection for teeth than light oils but still not as good protection as some of the compounds. Working on these lines we have developed units that are entirely splash lubricating; that is, the gear dips in whatever lubricant is chosen and splashes it into troughs which extend around the entire perimeter of the gear box at the shaft level, and from these troughs the oil feeds freely through openings in the sides of the bearings and circulates through them. For this class of work we have found that system very satisfactory. Thanks to certain improvements in lubricants that have been of more or less recent date, there are lubricants to-day that will flow freely at temperatures below freezing and with temperature and viscosity characteristics much flatter than those of the average high-grade mineral oil and with general adhesiveness and other characteristics which make them excellent gear lubricants. They are apparently fluid but they protect the teeth of the gears to a much greater degree than you could expect with a plain oil, and yet they will operate satisfactorily in bearings.

Now it is not my purpose to describe a particular lubricant. The field is open to everybody to look it over. I think it is generally true that most of the lubricating people are working on that problem, and it is a very important one. When a satisfactory lubricant can be found that will at once protect gear teeth against heavy shock and can flow freely through bearings and keep temperatures as low as they can be kept with oil, and keep down the wear and tear as well as oil, the art of gear manufacture will have advanced considerably and will be indebted to the lubricating people.

Mr. Twogood very kindly referred to the Falk coupling. This is not a coupling lecture and I will not enlarge on the subject, but I wish to thank him for his very kind reference.

H. H. Talbot:* A few days ago, I received a copy of the paper, with an invitation to take part in the discussion. Though I feel that the time I have been able to give to study of the paper hardly justifies an attempt at any sort of presentation, the subject of gears is always alluring and I will simply set forth some of the thoughts that occurred to me as I read it through.

The subject of high-speed gearing (over 4000 feet per minute pitch velocity) is somewhat outside of any actual experience as our field of endeavor, rolling-mill machinery, has to do with the heavier and more rugged types of gearing. However, for a certain continuous rod-mill which we are now building, the rolling speeds require pitch velocities up to 4000 feet.

As the paper points out, assuming the greatest degree of accuracy, the feature of the number of teeth in contact throughout the arc of action must have a considerable influence on the quietness of operation. This, of course, would be more apparent in spur gearing than in single- or double-helical gearing, though it does not lose its desirability in the latter.

Assuming standard stub tooth proportion, a 20-degree involute pressure angle, and given pitch diameters, we can not, by decreasing the pitch, increase the number of teeth in contact at any one instant. The addendum circles and consequently the arcs of action decrease as the pitch becomes finer and the number of teeth in contact remains the same within small fractional limits. Apparently the only way to accomplish this result is to lengthen the addenda and decrease the pressure angle. Here we find ourselves restricted by the standard hobs available. The American Gear Manufacturers' Association offers a long and short addenda system but the length of the addenda decreases as the number of teeth in the pinion increases, running out to no extra length over that of the standard stub proportions at 17 teeth. Very seldom do gears fail by tooth breakage. Wear is the great factor in the life of gearing. Then why is it necessary to sacrifice the value of the long addenda for pinions having any number of teeth?

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The long and short addenda system does add materially to the accomplishment of quiet operation by reason of the decrease of the arc of approach and the increase of the arc of recess.

This matter of the effect of bending and torsion upon the tooth contact, has always been to me very baffling. In the heavier class of gearing where the width of face rarely exceeds twice the pitch diameter of the pinion, and with the allowable tooth pressure, the deflection is nothing, but, in the class of work suggested in the paper, it must be a real factor to be reckoned with.

I have often pondered over these conditions but it is not yet apparent how contact across the full face can exist at all if we have appreciable torsional deflection in the pinion and none in the gear, as would be safe to assume. For the sake of simplicity, let us assume spur teeth. With torque applied at one end of the integral pinion, the deflection at this end section, of course, is zero and therefore this end of the tooth is in rigid contact with the gear tooth. As we step along the face, the successive points of contact of the pinion tooth are free to withdraw from contact, so to speak, due to the torsional elasticity. In other words, the ability of the pinion to keep its tooth in contact with the gear tooth decreases as we proceed away from the driven end. This results in heavy tooth pressure at the driven end section and a rapidly decreasing tooth pressure across the face. Correspondingly, the intimacy of contact decreases across the face. Now, actually, the teeth of both the pinion and the gear are themselves elastic. The portions of the teeth at the driving end, subjected to the greater pressure, will "give," thus tending to distribute the load farther across the face.

Suppose we had two identical slim pinions meshing together, and having the same torsional elasticity characteristics. We would then find that the contacting teeth of the two would similarly spiral in counterparts of each other, producing uniform contact and pressures across the entire face.

Ira Short:* The author stressed the importance of keeping the torsional deflection to a minimum in order to prevent concentration or loading on the teeth. In the discussion the question was asked if the helical angle of the pinion and gear had ever been made enough differ-

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ent to compensate for the torsional deflection such that at normal load the teeth would be in contact for the full face width.

With our small gears having the face width of pinions small as compared to the diameter, the torsional vibration gives us very little concern although care is taken to see that this is not excessive. On our larger power gears, for instance in powers from 500 to 35,000 horse-power, the face width of the pinions is generally large compared to the diameter and with this proportion torsional deflection can cause serious concentration of tooth loading if not given due consideration.

On the larger powers we use the floating frame construction which is used primarily for the purpose of maintaining correct alinement between the pinion and gear teeth. The pinion is supported by three bearings which are mounted in a heavy frame. This frame is very rigid in order to maintain the three bearings in alinement. The frame is fastened to the housing by means of two I-beams, the top flanges of the I-beams being bolted to the frame and the lower flanges being bolted to the housing. The flexure of the vertical web of the I-beams allows the frame to rock in a plane normal to a plane passing through the axes of the pinion and gear. This allows the pinion to follow the gear wheel and insures uniform loading on the teeth.

It is not generally known, but this construction also compensates for practically all the torsional deflection of the pinion. As described by the author, the end of the pinion at which the load is applied advances a small amount over the farther end. This results in a concentration of loading on each helix at the end of the helix nearest the driven end. With double-helical gearing free to move endwise, the total loading on each helix must be equal. We would then have two unequal moments about the center pinion bearing. One moment is equal to one-half the total tangential tooth pressure times the sum of the face width of one helix and one-half the gap between helixes. The other moment is equal to one-half the total tangential tooth pressure times one-half the gap between helixes. There is, therefore, a force equal to one-half the total tangential tooth pressure times the face width of one helix tending to rotate the pinion about the center pinion bearing. From this it will be seen that if the pinion be supported so that it can rock a slight amount in the direction this force is acting, the forces resulting from torsional deflection will automatically move

the frame until these forces are equal or the load is uniform. The floating frame construction allows this to take place.

A. R. Herbert:* Mr. Twogood referred to accuracy as being desirable in acquiring quiet gear operation. That applies of course to low-speed as well as high-speed work.

I have a few questions I should like to ask Mr. Twogood concerning the methods of obtaining checks and the various checks that are made. Later, I should like to discuss very briefly some of the checks that we make in an effort to determine why some gears are good and others are bad in respect to noise produced by the unit.

You stressed checks of teeth displacement as being the requirement, or one of the requirements, for quiet operation. Do you consider the check of contour and normal pitch necessary for quiet operation, and, if so, what tolerances do you believe should be observed? If we consider the plain involute for any pressure angle developed from the base circle, and consider a line of action tangent to that base circle, for that particular base circle and pressure angle we have an involute contour used as a tooth form. How much variation is permissible in that contour? How much variation is permissible in the normal pitch to obtain quiet operation?

E. N. Twogood: We think, of course, that unless you have a full face contact as well as a full line contact you will not get the benefit of the full arc of action. It is therefore necessary to have the teeth cut with sufficient accuracy so that the total contour of the tooth (as well as the length of the tooth) is in contact, and for high-speed gears we should maintain that same correctness of manufacture over the entire surface of the teeth that we find is necessary at the pitch line and which we check by the "pin-check" method described in the paper. Our experience indicates that this uniformity of spacing must be well within 0.0005 in order to have the unit operate satisfactorily. Also, unless these limits are maintained, full contact will not be obtained any more than if the bending and torsion are excessive.

A. R. Herbert: Referring to your method of checking, which we employ also, assuming that contact of pin is made somewhat close

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to the pitch-line and the top of the pin being above the outside diameter of the gear, it would be possible to obtain a correct reading at this point and yet have the normal pitch considerably in error.

E. N. TWOGOOD: Yes, that is true.

A. R. HERBERT: It therefore seems that it should also be necessary to check this contour.

E. N. TWOGOOD: We have no definite figures on that.

A. R. HERBERT: Is it because you do not consider it as important as the displacement check?

E. N. TWOGOOD: It is, as far as angular velocity is concerned. That has as much to do with noise as the other check and I think it should be considered as well.

A. R. HERBERT: I should like to ask if you attempt to maintain accuracy of normal pitch in the lock-train mechanism. You have spoken of the great degree of accuracy necessary in this mechanism. Do you check the normal pitch in that combination of gears?

E. N. TWOGOOD: At the time we manufactured them we did not have these checks available, and for that reason we did not check them.

A. R. HERBERT: What accuracy in hobs do you try to maintain for your high-speed work? The accuracy of course will vary to some extent depending on the particular part of the hob you are finishing. It will not be consistent all the way through the hob. Do you maintain very close tolerances?

E. N. TWOGOOD: We do. All our hobs when received are checked mainly by working templets and from these templets we check the involute curve which must come within the limits of accuracy required for quiet operation. Therefore, having the correct involute, the spacing is checked by the "pin-check" method at any point on the involute, which is usually, as I said before, at the pitch-line.

A. R. HERBERT: Then the degree of accuracy of the hob is dependent upon the degree of accuracy of the tooth cut.

E. N. TWOGOOD: Yes.

A. R. HERBERT: Is there any relation in high-speed work between load per inch of face and the hardness of the gear?

E. N. TWOGOOD: I think there is. There are two things to consider: (1) the material which you have has a certain elastic limit and the load on the teeth causes a certain deflection or stress at the roots of the teeth and, if the pressure is too great, the teeth will break out; (2) the surface stress or the ability of the material to hold its surface without deformity or wear must also be considered, and the ability of the material to hold its true surface does depend on hardness.

A. R. HERBERT: There seems to be a very definite relation between this load and the hardness.

E. N. TWOGOOD: I think there is.

A. R. HERBERT: It has not yet been defined in terms of the formula?

E. N. TWOGOOD: Only as we are using the elastic limit of the material with a suitable factor of safety in the formula. The ability of the cutting machine to cut accurate teeth limits the hardness of the material and we use the maximum hardness for accurate cutting.

A. R. HERBERT: Thank you. We are doing more or less checking of these various dimensions I have been referring to, contour checking and normal pitch checking as well as two displacement checks. At the present time we are carrying on an investigation to determine what effect those various checks or dimensions have on the quietness of operation of the gear unit. We try to be very careful in the tolerances of our hobs. I do not believe we can say except in a general way that a certain tolerance or error in a hob is going to cause this or that or something else. But we can say that if we hold the dimen-

sions of a hob to very close tolerances we have eliminiated one cause, or a possible cause, of trouble. Then we can turn our attention to some other phase of the work, as for instance the hobbing machine; but we like to know first of all that our hob is correct; and so we have prepared a complete list of tolerances to which we hold the manufacturer very rigidly. These dimensions are checked on a machine of special design built by the Illinois Tool Company. I do not believe there are very many of those machines in existence at the present time; just how many I do not know. Before we obtained this machine we had to accept what the hob manufacturer gave us and if it produced a good gear, all right; if it produced a bad gear, it was just too bad! Since we secured this machine we can dictate to the hob manufacturer as to what we want, and we do this and the result is that we are getting hobs to-day that are far superior to the hobs we were getting a few years ago before we had this machine.

I should say that there are four important dimensions to be checked in a finished gear. Of course some may differ as to the importance of these various checks, but in this investigation we are considering all of them—contour, normal pitch (I believe the American Gear Manufacturers' Association has sanctioned the use of the term base pitch instead of normal pitch), tooth displacement, and eccentricity. The contour check is a very interesting one because it shows us so much of the actual condition of the tooth. We develop the involute on the base circle. As you probably know, when we rotate the involute, any definite point in the involute will move along a tangent to the base circle. Now if we rotate this point through one degree of angular rotation, we can determine beforehand just how much a point on that involute should move along a tangent to the base circle. We compute that, and we obtain in a Detroit contour checking machine the exact movement and compare it with the theoretical movement. We plot that difference against the straight line representing the theoretical involute and we get a series of points which will show the variation in the contour from the true involute contour. A mean line drawn through a series of points will indicate the pressure angle of the actual contour. This pressure angle may be computed from the measurements taken.

I believe that the normal pitch measurement is coming to be thought of as a very important dimension. This measurement is the

distance along the line of action from one involute to the corresponding involute in the next tooth. I think Professor Buckingham in his book published within the last year or so has referred to the practice of varying the normal pitch between the pinion and the gear instead of using tip relief. I do not believe we have had enough experience to say to what extent that is satisfactory with high-speed work, but it seems to be a good practice. On a job on which we have been working we are confining our measurements primarily to the base pitch, holding to a tolerance of 0.0005 inch. These gears are being run on tests and the results so far have been very satisfactory. What the final results will be, of course, will be interesting to everybody.

We obtain the displacement checks in a manner similar to that discussed by Mr. Twogood, except that we do not use equipment of the sort described. In our plant we have been differentiating between the displacement check and the eccentric check; but I believe the displacement check should show the eccentricity as well as the displacement in a single check. That is done quite regularly, isn't it?

E. N. Twogood: Yes.

S. A. Staege:* Many of the points discussed by the author are of nearly, if not quite, equal importance in the design of gear units of more moderate speeds, of a class which may be termed "industrial gears." Pinion deflection and torsional deformation may not be such important factors, but general precision of construction must be rigidly adhered to in the production of quiet gears with long life, in continuous operation, even when pitch-line velocities are far below those under immediate consideration in the paper. Not only is it necessary that tooth contour, pressure angle, normal pitch, tooth spacing, and concentricity be maintained within approximately the limits indicated by the author for high-speed gears but parallelism of shaft, not only at the beginning but throughout the life of the unit, is of probably equal importance. Where anti-friction bearings are used in the gear units, it is of special importance that the lubricant be kept free from foreign matter—especially grit or metal particles. If, however, adequate precautions of this kind are taken and the unit is

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worked within safe and conservative units with respect to bearing pressures and tooth pressures, very long life can be reasonably expected.

A. B. Cox:* The point of this discussion that has interested me primarily is of course the integral-contact design feature which has been found to be so effective in making high-speed gears quiet. Briefly, the integral-contact principle consists in making the gears to have substantially two pairs of teeth continuously in contact—no more and no less—as the gears rotate; just as one tooth is leaving contact, another should be coming into contact. This method of designing has been mentioned here only in connection with high-speed gears. I want to say something about its importance in medium- and low-speed gears as well.

Two teeth in contact continuously give much greater strength than can be got with the usual single-contact design, and it has been found almost impossible to wear out such gears under what would be considered anything like ordinary loading. Some recent tests on unground hardened transmission gears showed an increase of more than 20 per cent. in the strength of the integral-contact gears over the standard 20-degree design, even though the pitch was decreased from 7 to 9. These tests were run in a manner that was somewhat unfavorable to the integral-contact design, but we wanted to be on the safe side. In wear tests, the transmission gears of ordinary design started out at 93.8 per cent. efficiency and increased rapidly to a constant value of 97.6 per cent. at the end of the test; the integral-contact gears began at 98.0 per cent. and increased slowly to 99.0 per cent. at the end of the test. The absolute accuracy of these figures can not be vouched for but, since these tests were made on the same dynamometer, the figures are truly comparative.

For quietness of operation, the chief difficulty that manufacturers have in applying integral-contact to their designs, is in getting sufficient accuracy in the gears, until they get tuned up to it. There is nothing that I know of, or have been able to find out from anybody else, that will take the place of a certain amount of accuracy in gearing. The gears must be accurate if they are to be quiet, but accuracy alone will not do it. However, since the necessary improvements to cutting machines, if gone about properly, can be made permanent

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without undue expense, such improvements are a profitable investment.

In any case, because of the greater flexibility of the teeth, inaccuracy in integral-contact gears is not so serious as in stub-tooth gears with their short inflexible teeth. In some cases of integral-contact gears we have figured out the amount of deflection of the teeth necessary to break them and found that it is considerably more than any amount of error that would be obtained in modern gear cutting. So, even though the load might start to concentrate at the end of one tooth, that tooth, before it could break, would deflect an amount sufficient to cause the load to come on to the next following tooth, which load would be applied near the root of the tooth and so give the gears the strength of a stub-tooth design, anyway.

The long life of integral-contact gears seems to be due to the division of the load pressure between two pairs of teeth, as well as to preventing the building up of excessive resonant pressures, so that the pressure between any pair of teeth always falls much below the critical wear pressure. I believe no one has definitely established the shape of this wear curve experimentally, but tests indicate that if pressure between the teeth is plotted as ordinates and wear as abscissæ, the curve will resemble a magnetization curve for iron, or a stress-strain curve for steel. Up to a certain rather definite critical pressure the wear is very slow, but if this critical pressure is much exceeded, then the gears wear out rapidly. Now when high-duty gears are designed to have two pairs of teeth continuously in contact, if there are inaccuracies sufficient to cause the load to be carried sometimes by only one pair of teeth, the load pressure between that pair of teeth will be much above the critical and that high spot will wear down very rapidly. But as soon as this high point has worn down sufficiently to cause the load pressure to be divided between two pairs of teeth, the tooth pressure falls below the critical and the wear automatically ceases, so that these two-tooth contact gears are to some extent self-correcting of the tooth form; and not only that, but the teeth do not wear out of shape and become noisy with long continued use. They retain their shape. An interesting account of some German tests by H. Hofer that showed these results experimentally is given in the *Zeitschrift des Vereines Deutscher Ingenieure,* for Oct. 1926.*

*V. 70, p. 1460.

Another interesting feature of the work with integral-contact gears is that it has been found practicable to operate with the contact very close to the base circle without any difficulty. The portion of the involute curve near the base circle is supposed to be, and probably is, very sensitive and very difficult to make accurate. Whether or not this part of the curve wears to a conjugate form different from the involute form has not been determined, but there are a number of gears operating under very heavy loads which have the contact almost at the base circle.

The particular thing that seems to explain the reason why integral-contact gears are so quiet is that all gears except integral-contact gears operate under a condition of mechanical resonance, some gears approaching the resonant point very closely. This is discussed in *American Machinist,* May 24, 1928.* If the gears happen to operate at such a load and speed that the torsional deflection explained by Mr. Twogood (which varies with the period of load change from one tooth to another as the gears rotate, and which also operates in helical gears as well as in spur-gears) happens to approach closely the natural period of some part of the driven machine, the gears will be very noisy no matter how accurate they may be.

For those who are interested in theory it may be interesting, in a heavily loaded gear set, to try to figure out the foot-pounds of work done, and to see how much work is available for producing noise, when the pitch-circle of the gear is moved one thousandth of an inch one way or the other from its normal speed position by a tooth error.

E. N. Twogood: I have nothing in particular to add. I am very much pleased to note that all agree with me so well. I wish to thank Mr. Day for bringing out the point about velocity. It is true that the variation of angular velocity enters a lot into the problem of good operation. However, for a lower pitch-line velocity we can allow greater errors or variation in angular velocity than for a higher pitch-line velocity; so, although the variations in the angular velocity actually govern the operation, the degree of variation must be less as the pitch-line velocity increases. It was for this reason that the pitch-line velocity was chosen to indicate the difference between the low- and high-speed gears.

*V. 68, p. 848.

STEAM DISTRIBUTION*

By R. C. Holley†

It is indeed both an honor and a great pleasure for me to be here with you to-day. In appearing before you, however, I am somewhat apprehensive of my ability to fulfil the conditions which this situation imposes. That is particularly true, when I recall the fact that the invitation to present a paper on this occasion was originally tendered to Mr. Walter J. Kline, who, no doubt, was known personally to some of you present. Since the time when he was invited to come to this meeting, he has most unfortunately been called to another sphere of activity. He was a very dear and intimate friend of mine for many years and for more than a quarter of a century was associated with the American District Steam Company, and during that period he was a deep student of district steam heating. At the time of his death last November, he was recognized as an authority on many phases of that subject; and so, from those of you who knew him, I will ask a lenient measure of criticism for this paper, which may not be all you could well have expected from him.

In contemplating a topic of this scope, an effort must of necessity be made to confine any discussion, at least partly, to that portion of the subject in which knowledge and familiarity have been gained by experience, for only therein lies the possibility of releasing some information that may be worth while.

In addressing such a distinguished assemblage as this, there can be no escape from the realization that probably all of those present are themselves fairly well posted with respect to any facts which may here be stated; and so, if this paper proves mostly a review of what you already know, it is not with intent, but by reason of treating a subject with which you are very likely familiar. So that this paper may assume a more definite character, its object will be to direct attention to the development and progress effected in the plan of distributing steam, primarily for heating purposes, through pipes laid under the surface of the ground.

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Steam distribution of this nature has now been successfully practised commercially for more than half a century, and while, naturally, many improvements and refinements in the methods of such distribution have been developed in that period of time, yet the principles followed in the early days were basic and still obtain at this date.

The initial attempt to convey and deliver steam through underground pipes to points located at distances from the source of supply was made in 1877, by what was then known as the Holly Steam Combination Company, Ltd. This name, after subsequent reorganization, was changed to American District Steam Company, as it now exists. By means of literature which has been published and sent out from time to time by the American District Steam Company, some of you, no doubt, are familiar with the story of how Birdsall Holly, a resident of Lockport, N. Y., and a hydraulic engineer of high repute, conceived in the year 1876 the idea of extending a steam pipe-line underground from the boiler in the basement of his home to the residence of a neighbor about half a block distant. To the wonder and consternation of many skeptics, the scheme worked satisfactorily and from this humble beginning quickly followed the organization of the original company, already mentioned, and the first installation in the city of Lockport, embracing about one mile of underground mains which served five stores, seven residences and two churches. The success which attended the venture was attested by the continuous extensions to the mains and the ever increasing number of consumers, until after an experience of two or three years of actual operation, the company embarked upon the plan of selling and installing similar heating systems in other cities.

If thus far the recital has seemed to be principally a history of the American District Steam Company, and not a treatise on the subject assigned, it is because the two are so closely interwoven that in any true descriptive account it is impossible to separate the one from the other.

The years which followed the formative period saw an intense effort to devise better and simpler methods of accommodating such contributing factors as expansion and contraction, anchorage, insulation, disposal of line condensation, freedom from leaks and underdrainage. The originators, with unflagging zeal have constantly endeavored to bring these details to a point approaching perfection, and

this effort, together with the general promotion work of the American District Steam Company, represents a cash investment of over three million dollars.

Reverting to the factors above enumerated, that of effectively providing for expansion and contraction was the most imperative. The first means designed found expression in what is now generally known as the slip-sleeve type of expansion joint, to be followed later by the packingless type of expansion device, that compensated for the elongation of the heated pipe through a corrugated copper diaphragm. This ingenious invention was given the name "variator" to mark a distinction from its forerunner. The step was a long advance, because the introduction of the "variator" permitted the elimination of manholes, which had previously been necessary wherever slip joints were employed.

The question of anchorage was likewise of essential importance for by so constructing a pipe-line as to provide alternate points of anchorage and expansion at predetermined intervals, the movement of the line when heated was directed towards the expansion devices that allowed for such movement. Moreover, both types of devices furnished the means whereby lateral service connections to adjacent buildings could readily be extended, it having then been considered best to take service connections from fixed points in the line.

Insulation of the pipe-line is very closely associated with the quantity of condensed steam which will form in such a line. Many long and searching experiments with a great many different kinds of materials were conducted to discover how best to insulate underground steam mains. Of course, it must be borne in mind that during these earlier stages of development, consideration was given only to the transmission of steam under low pressure. The conveyance of steam at high pressures and temperatures is an accomplishment of very recent years. After a great number of tests and observations, it was found that kiln-dried wood, preferably cedar or white pine, proved to have insulating qualities superior to all other materials, when combined with a dead air space between the inside diameter of the wood log and the outside diameter of the pipe. Originally, solid logs bored out to the correct size were used, but these subsequently gave way to casing built up of wood staves. By this method of insulation, line condensation, which is the greatest thief of efficient steam transmis-

sion, could under capacity load be kept at a minimum, not exceeding 7.8 per cent. of the total amount conveyed. In addition, this type of insulation acted as a conduit for the steam main.

A very vital feature, which at first received rather scant attention, is that of underdrainage. It required several years of actual experience to reveal the absolute necessity of providing for the rapid and complete draining of the entire underground area surrounding the pipe-line. This was quite readily effected by supplying a bed of coarse gravel or crushed stone at the bottom of the trench, including one or two lines of farm drain-tile four inches in diameter, as the particular case might warrant. Such underdrainage construction, together with a roofing of four-ply tar paper over the top of the wood casing, insured a line free from under-surface water and was a practical guarantee of long life for the entire installation. In this connection it might be interesting to relate that in 1922 the Lockport Light, Heat and Power Company was faced with the necessity of replacing about 400 feet of four-inch line with six-inch line, as the capacity of the original installation, laid in 1884, had become heavily overloaded. When the four-inch line was uncovered, the wood casing and the entire line were found to be in such an excellent state of preservation that they were carefully removed and relaid in another location.

The story here unfolded would not be complete without particular attention being directed to the very important part played by the disposal of line condensation. The freedom from water accumulation in the line was recognized from the beginning as a necessity to satisfactory operation. Such disposal was, naturally, predicated upon all mains being laid to grade, with low points established where conditions dictated and bleeder connections including traps provided to permit the easy release of the condensation. Subsequently, the metering of this line condensation supplied most valuable information with respect to the amount of steam lost through this channel.

The foregoing summary brings us, perhaps, through the first three and one-half or four decades of the life of the industry, and to the period of time when underground construction began to contemplate the employment of pipe-lines for transmitting steam under high pressures up to 250 pounds gage.

The advance into this field required a number of sharp changes in the practice that had become standard in low-pressure work. Almost

the first problem to be solved was that of expansion, for the great increases in temperature and superheat which accompanied the higher pressures called for expansion devices of different design from those previously used; but the ample fund of knowledge gained through all the long preceding years served to point the correct way, so that in a comparatively brief period there were brought forward the types of devices which the altered conditions demanded. Again, due to the high temperatures, it became necessary to abandon wood as a means of insulation, and in its place have been substituted the built-up conduits of "Multicell" tile, concrete, brick and split tile. But, perhaps, the one single thing, more than all others, that has made possible the successful handling of steam at high pressures, was the introduction of welding and the consequent elimination of screwed or flanged joints. It may probably be stated with no fear of contradiction that without the availability of the welding process, the satisfactory construction of underground pipe-lines for high-pressure steam transmission would be a remote possibility. So attractive have been these latter-day ventures in the manufacture and sale of high-pressure steam, that at the present writing there are in a considerable number of the larger cities, such as Boston, New York, Philadelphia, Baltimore, Pittsburgh, Cleveland, Akron, Indianapolis, St. Louis, Kansas City, St. Paul, San Francisco, Portland (Oregon) and Seattle, very extensive district heating systems representing invested capital totaling many millions of dollars.

The first years of development were concerned with boiler plants built for heating purposes only. Then followed a period with a heavy trend towards combination plants generating electric power and light with the use of exhaust steam from the prime movers for the heating supply. Such an arrangement, during the time of low-pressure distribution, was looked upon as the ideal condition. Now, with the advent of high-pressure steam transmission, a profitable field has again been opened to direct heating activity. Especially is this so, because of the lessening of the initial cost of underground installation by reason of smaller pipe sizes for any given load. Furthermore, let it be made clear that many consumers enjoying service from high-pressure mains make use of the steam at full pressure for power purposes, so that, strictly speaking, the term "direct heating" is not all-inclusive. Many plants of both types are at present operating with marked success, and

as an illustration of what can be accomplished, with a combination set-up, the following figures from a report just recently received, are offered:

Number of consumers	402
Plant investment	$278,198.94
Boiler investment	100,000.00
Gross income	179,844.84
Operating expense	126,705.28
Net income	53,139.56
Operating ratio	100:70.43 per cent.

In a previous paragraph, passing reference was made to the various forms of built-up conduit which have been substituted for wood insulation where high-pressure steam lines are to be installed. When such mains are in service, there can be no question but that considerable temperatures are created inside the walls of the conduit, dependent, of course, on the temperature of the steam in the pipes. That these temperatures are, at times, sufficient to cause expansion in the conduit has been conclusively proved, and attempts have been made to provide some suitable means to care for such expansion. As yet, however, there seems to have been no satisfactory method devised to meet this condition, at least in the conduit construction itself. Considerable success, nevertheless, where straight runs of conduit are concerned, has attended the practice of allowing a free end to the conduit where it enters a manhole housing. Whether the manhole inclosure be constructed of brick or concrete, it has been demonstrated conclusively, that by avoiding any fixed bond between the wall of the manhole box and the walls of the conduit, there is afforded freedom for movement of the conduit without any resulting damage. Of course, some type of flexible bond must be provided between the outside surface of the conduit and the wall of the manhole, to guard against seepage water. A period of further experience in work of this character, and the constant study of such details by the original company, whose continuous endeavor is always looking in the direction of betterment, will undoubtedly result in bringing more and lasting improvements to methods of underground construction.

Let us now turn briefly to the actual distribution of steam to the consumer, for it then becomes a sale, which is the desired objective.

Several so-called systems of interior piping are in vogue, but the vapor or atmospheric method, operating on a few ounces of pressure, is probably the one that to-day is most generally employed. In this respect, it is interesting to observe that Mr. Birdsall Holly, who first conceived the idea of district steam heating, designed and placed in service almost fifty years ago, a system of piping which he termed "atmospheric," and, from this, the present vapor systems have been developed. The inventor's idea took form before the days of cast-iron radiation and, to meet the requirements, he had radiators fashioned from tin, formed like huge pads six feet long by five feet high and four inches thick. These were reinforced by stay-bolts passing through the device from front to back, so that the outer appearance resembled that of a tufted quilt. These unique radiators had supply connections in one end at the top and discharge openings in the opposite end at the bottom, and thus antedated by almost half a century the modern accepted style of cast-iron radiation with all sections connected at the top and bottom.

For many years, the charge to the individual consumer was either on the basis of the square feet of heating surface installed or the cubic feet of space in the building. Later, however, the inventor, whose attention was ever bent upon further advancing the venture in every particular, designed and had manufactured what was known as the Holly steam-flow meter for measuring, at the entrance of the service line to the building, the amount of steam supplied. Then followed the idea of measuring the quantity of steam after it had been used by the consumer, and this gave rise to the development and manufacture of the various types of condensation meters, generally in use to-day, with which most of you are no doubt familiar. As an added commentary, it may be stated that with the advent of the distribution of steam at high pressures and often with a marked content of superheat, there has come the necessity of again introducing a steam-flow meter in the service connection, for properly registering not only the pounds of steam but the total heat delivered, for the latter would be the only fair way of basing a charge for the service. Then, with the rate on a graduated or sliding scale, commencing with an upper price for peak demand, which would prevail in early daylight hours each day, and diminishing as the day advanced and various buildings had been brought up to temperature, an automatic check would be placed upon

the use of steam at the power-plant. Paradoxical as this statement may appear, the explanation lies in the fact that buildings would most likely be maintained at more even temperatures, rather than allowing them to cool down during the hours of darkness. A resultant smoothing of the load curve at the power-plant would bring a distinct advantage in reduction of boiler investment as well as operating costs.

In conclusion, and as the final thought to leave with you, prominent place must be given to the fact that an adequate rate structure is of essential importance in the successful operation of a district steam heating plant. Rates for the sale of the product should be determined only after a thorough study of all the contributing conditions, keeping in mind that rate schedules can much more easily be decreased than advanced. Quite common practice, at the present time, is to introduce what is termed a "coal clause" so that rates can automatically vary with changes up or down of the price of coal delivered to the boiler plant. Too much emphasis can not be laid upon the supreme significance which the rate structure bears to the entire project.

The subject of steam distribution has many ramifications and as announced at the outset, the range of this paper has been limited, but the endeavor has been to discourse upon the salient features of district steam heating as an engineering study and a practical and ever expanding industry.

DISCUSSION

Dwight L. McNulty:* Mr. Holley has given you an insight into the growth and development of the central district steam heating business, and has touched briefly upon some of the major problems encountered in distributing the manufactured product of that business.

It is my intention, among other things, to elaborate somewhat upon Mr. Holley's remarks in order to bring home to you more forcibly a few of the interesting problems that present themselves for solution during the design and construction of the physical equipment for concerns engaged in the manufacture and distribution of steam.

First, let us briefly consider some of the features peculiar to central district heating systems. The load-factor is usually very low.

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There must be sufficient boiler capacity, and the mains and services must be so designed as to serve all customers on the coldest day of the winter. This means that the facilities must have perhaps a 50 per cent. larger capacity than would be required for the *average minimum* temperature expected to occur.

Other important points to be kept in mind in laying out a complete system are, reliability, growth, ultimate size, the type of construction to be followed, the materials to be used, and others many of which in times past have been given less attention than they deserved. Now, with this introduction, let us consider some of the problems that arise in designing and constructing the underground work.

Before a given major extension of the distribution system is made, it is necessary to consider carefully not only the immediate load it will serve, but the probable service that it must ultimately furnish —often a more or less shrewd guess. Having arrived at this, a route must be tentatively selected, and the pipe sizes determined before actual design for construction can be commenced.

The next question—that as to the type of envelope to be used for protection of the mains—very often solves itself in Pittsburgh. On many of the streets here, the tunnel method of construction for the larger mains is dictated by the narrow streets already so congested with the service facilities of other utilities—telephone, telegraph, electric, gas, water, and sewer—that to find sufficient additional space for the steam and return mains in some form of conduit laid in an open-cut trench is impossible at a reasonable depth; and to handle the open cut for such construction to a sufficient depth to gain a straight run is not only more costly than to tunnel but takes more time and obstructs traffic to a far greater degree, thereby not enhancing the relations between the company and the public.

It is evident that, though tunneling is costly, and is usually to be avoided when other means of construction are feasible, this method of construction offers some distinct advantages. Had the open-cut method, instead of the tunnel method been resorted to for the construction last year of the Allegheny County Steam Heating Company steam and return mains between the new Twelfth Street steam station and the system loop, any of you who traveled on Twelfth Street, on Penn Avenue between Twelfth Street and Tenth Street, or on Tenth Street, or William Penn Way between Liberty Avenue and Seventh

Avenue, would have been much more hampered in your movements. A tunnel permits a permanent walking space, thereby facilitating the inspection and maintenance of the equipment, and at the same time presents an opportunity to provide sufficient space for the reception of future mains that are bound to be required.

The tunnels themselves require careful study in order to provide the most satisfactory and economical arrangement. As recently designed by us, the tunnels proper contain nothing but straight pipe on roller supports; all expansion devices, valves, traps, and other accessories being located in vaults, or manholes as we called them until the "city fathers" told us they were much too large to go by that name.

The location of the tunnel must be such, among other things, that it clears all subsurface obstructions, for it is by no means as easy to shift the direction of a tightly sheathed tunnel to clear an obstruction that may be encountered, as it is an open-cut trench. To ascertain where these subsurface obstructions are located is another problem, and a tedious one. First, a careful surface survey is made and plotted to locate definitely all visible evidences of hidden obstructions, such as manholes, valve-boxes, etc., both on the route selected and on all cross streets for about a block on either side. Then the visible information below the manhole covers is measured and plotted, this information oftentimes being obtained at night so as to interrupt a minimum of traffic. This information, together with that gleaned from old plans, coupled with assumptions where necessary as to what course a given service might take between manholes, supplies the necessary data upon which to base a decision as to where the tunnel may be located; and many times where it can not be located if the vaults are to be brought up to the street level without moving many of the other utilities in the street at every vault location. The design of the vaults presents among other items, the following of interest:

1. Where should each be located:
   a. To house the pipe-line accessories?
   b. To make the best provision for taking off branch mains?
   c. To serve best during construction as a tunnel heading for the removal of the spoil, etc., with a minimum of annoyance to the public and adjacent property owners? (Not all, of course, are used as headings.)

d. To be most accessible when completed, traffic conditions considered?

e. To avoid underpinning the foundations of an adjacent building because the angle of repose between the foundations thereof and the bottom of the vault excavation is too steep?

f. To fulfil all of the above requirements? (Often an impossibility.)

2. How large should this vault be; and what shape is necessary so as to permit—after the concrete is poured, and the street repaved—the introduction through the manhole frame of pipe in lengths of say 20 feet or so, and the bulky valves and expansion joints?

3. With the above questions in mind, how must it be designed structurally to give the desired space and clearances in the determined location, and support a street load of 1000 pounds a square foot, and how designed so it can be constructed under, say a hundred-year-old, large-diameter brick sewer, and several existing manholes without accident, or untoward expense?

Mr. Holley has mentioned the importance of underdrains to carry away any water that may collect around the conduit. In some portions of our tunnel work here we have had a more difficult problem; that is, when a tunnel is driven through sand and gravel parallel to the river and one block therefrom, with its floor at approximately the same grade as normal river level, how both to provide for the expansion and contraction of long runs of concrete tunnel and at the same time prevent the ingress of water in damaging amounts into the tunnel at times of high water. Underdrains, in this case, would accentuate rather than ameliorate the trouble. We think that we have now found a satisfactory and inexpensive solution to the problem. We have made sufficient observations to know that, in this type of service, concrete will expand and contract, if given the opportunity, and is much more likely to crack due to contraction if means are not provided to prevent this.

I agree with Mr. Holley as to the necessity of pitching the conduit and pipe runs to provide adequate drainage.

The matter of providing adequate means for caring for the expansion and contraction of the pipe-lines has not been overempha-

sized in the main paper. There are, to my knowledge, five different methods of doing this:

1. Expansion bends. These are very seldom possible, and less often feasible in underground work, except for very small amounts of movement such as might occur in cross-over connections and the like in vaults.

2. Swing joints. These are subject to the same objections as expansion bends, as well as being more subject to leakage.

3. Bellows joints. These are usually of copper.

4. Diaphragm devices, or "variators," as mentioned by Mr. Holley. To date, the diaphragms have been made of copper. Recent tests that have been called to my attention, confirmed my previous suspicions that copper possesses a comparatively short life under reversals of stress such as obtain in this service. This same disadvantage is common also to the bellows joint. I have been given to understand that the company with which Mr. Holley is connected has developed, and is ready to market, an improved type of "variator" with special steel diaphragms that have many times the life of the copper diaphragms.

5. Expansion joints of the slip-tube type. Sturdy, well guided joints of this type, of the proper material for the service, and packed for the existing conditions, will take care of large amounts of expansion such as occur in long straight runs of pipe carrying steam at comparatively high pressures and temperatures, for less cost in most cases, I should say, than any other method.

One thing is important, and that is that no expansion device, except the bend, or swing joint, of course, will function properly unless the pipe-line between the anchor and the expansion device is straight and well supported so as to be free to move toward the joint. The joint too must be accurately alined with respect to the pipe. It does not pay to try to force a pipe carrying high pressure steam, particularly, to expand around a corner into an expansion device. If such a design functions as intended (as it more often will not), luck is undoubtedly in league with the designer. I will admit that we have found this expedient necessary in a few instances in placing lines in some old tunnels that were constructed anything but straight, by a contractor; but, in these few cases, every conceivable precaution was taken to insure the desired results with safety.

It might be well to mention the fact that our experience seems to indicate that with well guided slip-tube expansion joints and free-rolling pipe supports designed to prevent side motion of the rollers, with the proper amount of care exercised by the construction crew in obtaining accurate alinement, pipe guides external to the joint seem to be an unnecessary adjunct. I do not, however, mean to imply by this that guides are never desirable.

The question of substantial anchors can not be too much stressed. Too often this is not given enough thought by the designer, with the result that the inevitable happens—the anchor fails, and perhaps the slip tube is pulled from the joint body, or the copper bellows is pulled apart unless something intervenes. Consider for a moment, a high-pressure steam line 24 inches in diameter and half an inch thick, with an internal cross-sectional area of 415 square inches. When carrying steam at a pressure of 250 pounds per square inch, there is a total internal force of 103,750 pounds acting longitudinally. If this pipe-line were a tank of the same diameter, there would be a longitudinal tension in the walls. But suppose the manufacturer had forgotten to rivet or weld the girth seam, and had merely inserted one half of the tank into the other, would any of you question the fact that the two halves would be blown apart, unless there was an external force applied to either end of the tank acting toward the center, each of a magnitude of 103,750 pounds? I think not. That is exactly the condition existing with a slip-type expansion joint in the 24-inch steam main. The external force applied on either side of the expansion joint should be supplied by an anchor amply substantial to withstand the separation stress of over 100,000 pounds. We have in the Twelfth Street tunnel a 250-pound main 24 inches in diameter. This steam line is supported on structural steel over a 16-inch, flanged, cast-iron return main beneath it. You can readily realize that it takes more than just a few pounds of structural steel for each anchor. The only resistance that the slip-tube joint itself offers to the separation thrust is the friction between packing and sleeve, which, if the joint is to take the expansion of the pipe freely, will be very small indeed, and should be neglected. By the same token, the inconsequential resistance offered by the other types—about 125 pounds per square inch of diameter in the case of the bellows—should also be neglected in high-pressure work.

I hope that the man who invented autogenous welding will receive his just reward in the next world if he has not already in this —it is certainly a money saver.

I might state that all of our recent pipe work in conduit has been welded, and all recent lines in tunnels have been welded, with the single exception of the gravity condensate return which, as I have before stated, is of flanged, cast-iron pipe. We find that this resists corrosion better than does wrought-iron pipe, and the flanged joints in the tunnels are not objectionable for there is almost no pressure on the return. Welded outlets are provided wherever possible instead of fittings. On all wrought-iron lines of any size, it is our present practice to use as few joints as possible, to locate them all in vaults (or other accessible places) and to make them of the vanstone type.

Before leaving the subject of welding, I want to touch upon the annealing of welded joints. We have never resorted to that practice, nor have we ever had a weld fail, but I believe annealing might be advantageously employed on the larger and more important mains. Welding a split sleeve around the butt weld would, in my opinion, entirely counteract the effect of the annealing. The manufacturers of welding equipment have made rather extensive tests on the strength of welded joints, and these tests seem to indicate that the weakest part is in the pipe adjacent to the weld rather than in the weld material itself, the welding operation having altered the structure of the metal adjacent to the weld. The object of the annealing is to permit that structure to return to its original state. The welding of a split sleeve over the annealed butt weld, as mentioned by Mr. Holley, results in structural changes in the pipe at either end of the sleeve similar to those occurring adjacent to the butt weld; so it is probable that, instead of strengthening the annealed joint, the added sleeve has weakened it.

Mr. Holley has given you, perhaps, the impression that wooden pipe is immune to attack by the elements. I have heard of several cases, however, where it rotted away because of adverse soil conditions.

I was very much interested in the figures Mr. Holley presented as to what steam-heating companies can do in the way of earnings. Lest some of you are planning to leave here and invest your money in some new district heating venture, let me point out to you that you will probably not be able to serve your customers with as low an

investment as that of Mr. Holley's example—$942 per customer. This is very very much lower than that invested per customer in any other steam-heating utility of which I have knowledge. The operating ratio, however, seems sufficiently high to include, perhaps, a sum of money for the rent of leased facilities. It occurs to me that the $100,000 for the investment in boiler plant is an arbitrary share of a complete plant investment pro-rated to the steam-heating business, and very probably is not sufficiently high.

R. C. Holley: May I just speak again with particular reference to the last remarks of Mr. McNulty made as to the example that was put before the meeting of the operating company whose showing was so good. We do not often get full operating statements. In this particular case, it was not so many years back that this same company was operating at a loss and its great recovery in this respect is outstanding in showing what can be done when proper attention is given to the project, with all the necessary thought to make a paying venture out of what was formerly a losing one.

R. L. Kirk:* I should like to ask the speaker if they did not reduce the steam-heating cost by putting in a by-product electric machine. You say $100,000 was allocated to the heating system. How much of the total plant investment was charged to the electric end? Being an electric man, I wonder whether they did not make the electric end carry some of the heating costs.

R. C. Holley: You know just as much about it as I do. These are the figures that were transmitted to us and I assumed from the very nature of the amount set over for the heating system that it was entirely arbitrary. To just what extent it is a proportion of the whole I do not know.

To continue, with reference to what Mr. McNulty said in relation to the surrounding sleeve or reinforcing band, personally I am entirely of his opinion. I think whatever good might be supposed to take place from that reinforcing element is entirely offset by the fact that you are subjecting the pipes to the same stress and strain you are trying to remove by your annealing process. And the strength that is

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regained by the restoration of the material is all you can hope to secure by the annealing process. Any further addition, like the strengthening band, is I think entirely without any compensating worth. As I stated in the paper, the American District Steam Company supplied what the customer wanted, but did not advocate the use of the reinforcing band.

B. M. Herr:* I would like to ask Mr. McNulty if he is not of the opinion that the installation of a steam-heating main in a district like Pittsburgh, where you have a rise and fall of rivers to contend with, is considerably more of a problem and more expensive than it would be in many other cities.

Dwight L. McNulty: From observation of the properties of other companies, I believe that the conditions for the construction of underground mains in Pittsburgh and New York are probably among the worst in the country. Pittsburgh streets are very narrow and highly congested, and in many cases have two street-car tracks each. In New York City they have very little tunnel construction. In many places there the main lines are squeezed into conduits between the tops of the subways and the surfaces of the streets and all the other utilities are there too.

In any city work the cost of the conduit work and the excavation and repaving incidental thereto always exceeds, I believe, the cost of the equipment which the conduit contains. Often the straight runs of pipe between vaults amount to a very small part of the total job. It seems to me, therefore, that additional money expended to obtain pipe materials better suited to the service will make no very material increase in the total job costs; and that the structure itself offers the best opportunity for the possibility of an investment saving.

W. B. McQuiston:† I should like to ask whether the proposed subway would affect your conduit tunnel.

Dwight L. McNulty: Two or three years ago, when we crossed Sixth Street with the Penn Avenue tunnel, we tried to find

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†Salesman, Kier Fire Brick Co., Pittsburgh.

out what provisions we should make for the proposed city subway on Sixth Street. We were told that possibly Horne's store, the Jenkins arcade, etc., might want to extend underground passages to their stores from the proposed subway station at Penn Avenue and Sixth Street. We did keep this in mind in constructing the tunnel, but could obtain no additional detailed information, because the matter was then so unsettled. We located no vault within 100 feet of Sixth Street, when we were advised that we might have to relocate the tunnel at Sixth Street if the subway were built.

T. E. Purcell:* I am sorry this meeting has not developed, in more detail, the economic and engineering features of transmitting steam, more particularly in steel-mills and other industrial plants.

The Allegheny County Steam Heating Company's engineers have endeavored to locate steam lines so as not to interfere with any future subways. A great deal of time was spent with the City Transit Commission, appointed by the Mayor, which has been studying the subway situation for many years. This Commission co-operated wholeheartedly with us, so that we now believe there will be very little, if any, interference between our steam lines and the subways. For instance, we had planned some years ago to install a large steam line under Liberty Avenue, but, as this seems to be one of the streets under which a subway may be constructed, we changed our plans and have built a line under Penn Avenue.

The figures Mr. Holley presented, giving the cost of operation, apparently do not tell the whole story. I doubt if taxes, insurance, depreciation, or interest on the money invested are included in the figures given. I am familiar with the income and operating cost of many steam-heating companies and I assure you none, with which I am familiar, is making very much money. The investment per dollar of income is very high, due, in most cases, to the cost of underground construction. Here in Pittsburgh our engineers think that we have problems not encountered elsewhere, but we hear the same story from other cities.

It appears to me that the present methods of transmitting steam through pipe-lines leave much room for improvement. We are still working along lines, which, as Mr. Holley stated, were started some

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fifty years or more ago. At the present time the steam-heating engineer looks upon 200 pounds as high pressure, whereas the power engineer is already working with 1800 pounds pressure. Perhaps in the near future, as the distance which steam must be transmitted increases, steam will be started on its way at pressure several times that now considered good practice. Years ago the electrical industry looked upon a few hundred volts as high voltage, whereas to-day transmission lines are being operated at more than 200,000 volts.

Of course a radical increase in pressure will mean that some of the present equipment, such as the slip-type expansion joint will probably have to be abandoned. Just what will replace it, we do not know, but certainly something can be developed.

R. C. Holley: I think some of Mr. Purcell's remarks are quite apropos. We are going through a period of development that is difficult to realize at the present time. Just what steam distribution is best, with regard to initial pressures, is difficult to state. When I spoke of 250 pounds as high pressure, it was only relative as compared with what we have been accustomed to handle in days gone by. There is perhaps no reason to think that in the years to come such pressures may not develop higher and higher and even reach the degree that Mr. Purcell has mentioned. If we can provide the means to handle steam at higher pressures we will be able to cut down our pipe size and yet serve the same amount of load. Just where high pressure will end is a matter of conjecture at the present time and one person's opinion is worth just about as much as another's.

Dwight L. McNulty: As to the external pipe guides, I did not mean to say that they are not desirable in many cases. If the line is placed in an open-cut trench, with the manholes and conduits all on the same subsoil, where each has an equal chance of settlement, guides might well be used. In tunnel work, where the tunnel is driven under streets with sheathing surrounding the structure, and the floors of the vaults (built in open cut) rest on virgin soil, the tunnel may settle while the vaults may not, in which event the guides will be carried down with the tunnel, thus forcing the pipe out of line, instead of maintaining the alinement. That is the thought I had in mind when I made the statement regarding external guides.

R. C. HOLLEY: I think every situation has its own conditions to meet, as we have experienced time after time, and what might be good medicine in one place might not be the remedy at all in another; but a manufacturing company like ours must necessarily have some standard to follow wherever conditions warrant. In regard to the installation in which we are now engaged at Shawinigan Falls, it is certainly quite unusual for us to install 3500 feet of steam line and not have in it any of the devices we manufacture; but that particular line being above ground where space does not make any difference, and the purchaser manufacturing a product used in acetylene welding, you see the situation has its own conditions that every designing engineer would have to consider.

J. L. MCCULLOUGH:* Mr. Purcell said that he thought and hoped that this paper would develop into a discussion of the economics of steam distribution as well as the engineering side of it. As a matter of record I should like to say that my work during the last year as Chairman of the Sales Promotional Committee of the National District Heating Association has pointed out forcibly that there are two schools of thought in the central-station steam industry—the bulls and the bears. This work has indicated to me that the tendency is towards the bull side of the market more than towards the bear side. Each year there are more indications of profitable operation of central-station steam properties, and each year more healthy profits are shown by those companies which are progressive and well managed, as in the local utility.

The original idea of central-station steam was to give a service which would take the place of exhaust steam from engines in the individual office buildings in congested down-town districts where it was desirable to close down the electric plant. That was the inception of the central-station industry as we know it to-day, but the industry is broadening and many properties are being considered in districts where the acquisition of the electric business has little or no effect.

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CONSTRUCTION OF CONCRETE RESERVOIRS WITH SPECIAL REFERENCE TO FOUNDATION WORK IN ABANDONED MINES*

By R. M. Riegel† and G. L. Hendrickson‡

INTRODUCTION

The City of Pittsburgh under the bond issue of 1926 has been overhauling and amplifying its water-supply facilities on the North Side. Prior to the program of improvements the North Side district was served by reservoirs or tanks at four levels. The distribution divisions were known as the lower or Cabbage Hill service with reservoir at elevation 275 above city datum; the second level, that of the so-called Montgomery and Spring Hill tanks at elevation 502; the third, the Lafayette service with tanks at elevation 584; and the fourth, the Greentree service with tanks at elevation 692.8.

Excepting Cabbage Hill, the services were regulated by steel tanks of various capacities, those for the upper three levels having a gross capacity of 1,545,000 gallons. This represented, with reference to the average demand of the districts served, a storage of only 4⅜ hours supply. In the Montgomery and Spring Hill districts the storage with reference to population was actually much less than the average, while in the Greentree service it was considerably more. These tanks, except Greentree, prior to the program of improvement were served from the Howard Street pumping station by steam-driven pumps taking their suction from the Cabbage Hill system. The Greentree tanks were served by an electrically driven booster station, drawing its suction from the Lafayette system.

The bond issue of 1926 authorized improvements to remedy this North Side situation. Howard Street station was re-equipped with electrically driven pumps and provision was made for pumping direct from this station to the Greentree elevation, dispensing with the existing Greentree booster station. Some additional pipe-line work was authorized and has been constructed, but the most important feature, from a monetary standpoint, was the increase of reservoir

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capacity. The new Brashear and McNaugher reservoirs, to be discussed in this paper in more detail, together with new tanks for the Spring Hill service, have afforded a gross storage of 17,000,000 gallons, which is, with reference to the average demands of the districts served, a storage of about 48 hours, or approximately ten times that previously existing. The largest item of storage (10,500,000 gallons) will be at the highest level, where in an emergency it can be fed to the lower levels. The Bureau of Water is not yet satisfied with its reserve on the North Side, but hopes when funds are available to duplicate the high-level installation at the Brashear site and thus obtain about 50 per cent. of additional reserve or about 72 hours supply.

The reservoirs, as well as the general bond issue program, are administered by the Department of Public Works, of which Edward G. Lang is Director, and Charles M. Reppert, Chief Engineer. The Bureau of Water, as a division of this Department, is in charge of E. E. Lanpher, Managing Engineer, and the Distribution Division is directed by J. H. Kennon. The writers of this paper, as assistants to Messrs. Reppert and Kennon, co-operated in the design, although Mr. Hendrickson developed the details of the design and also was in active charge of the construction of both reservoirs. All of the above mentioned engineers participated in the principal decisions on the work.

Sites for Reservoirs. The principal site available was that now designated as Brashear Park, occupied for twenty years by the so-called Greentree tanks, which serve a population of about 3000 in the high district immediately adjoining. (This site lies east of Perrysville Avenue at the northern city line and is the highest ground in the city.) The site has long been held by the city for reservoir construction and has been occupied by the small steel tanks for some twenty years. The peculiar ability of this site to serve the high-level district rendered it necessary to utilize it almost regardless of any disadvantages which might attach to it from the standpoint of construction.

The topography lent itself to the enlargement of the Montgomery and Greentree pressure districts (renamed the McNaugher and Brashear services), absorbing the intermediate Lafayette district, and thus permitting the elimination of one set of pumps and one

storage unit. The present demand of the new McNaugher district far exceeds the present demand of the Brashear district, but considerable study of the reservoir problem made it evident that the bulk of the storage would have to be at the Brashear site, with the McNaugher site developed as fully as was financially feasible. It being necessary to get an elevation for this latter reservoir immediately between the existing levels of Lafayette and Montgomery tanks, the choice of site was somewhat restricted. However, some six alternative sites were examined and finally a site closely adjoining the Lafayette and Montgomery tanks was selected.

Coal Veins in Sites. The interesting fact developed that on every site which was available for reservoir construction and suitable in a topographic way, there was present near the top of the hill partly worked veins of Pittsburgh coal. Consultation with the state Geological Survey and examination of other geological data, as well as field examination of available reservoir locations, indicated that no site at suitable elevation and free from coal could be secured without going outside of the city far to the north, incurring heavy pipe-line costs as well as material losses of head for pumpage. At the two selected sites, as well as the possible alternatives examined, it was found that the coal workings were very old. At the Brashear site, for instance, the city has owned the land in fee for years and there was no legal record of the coal ever having been sold; yet an examination of the site showed that it had at some time or other been entered by a half dozen drifts at different places and that the coal was in fact largely gone. At the McNaugher site the old drifts were not much in evidence, but our borings showed a similar condition.

BRASHEAR RESERVOIR

It being evident that Brashear Park must be used for storage regardless of the presence of the old mines, a contract for making diamond-drill borings was made with the Pennsylvania Drilling Company of this city. These borings showed the geological structure indicated by Fig. 1—a heavy bed of rock about 60 feet in thickness between the floor of the proposed reservoir and the top of the coal horizon, this roof being predominantly a hard sandstone with, how-

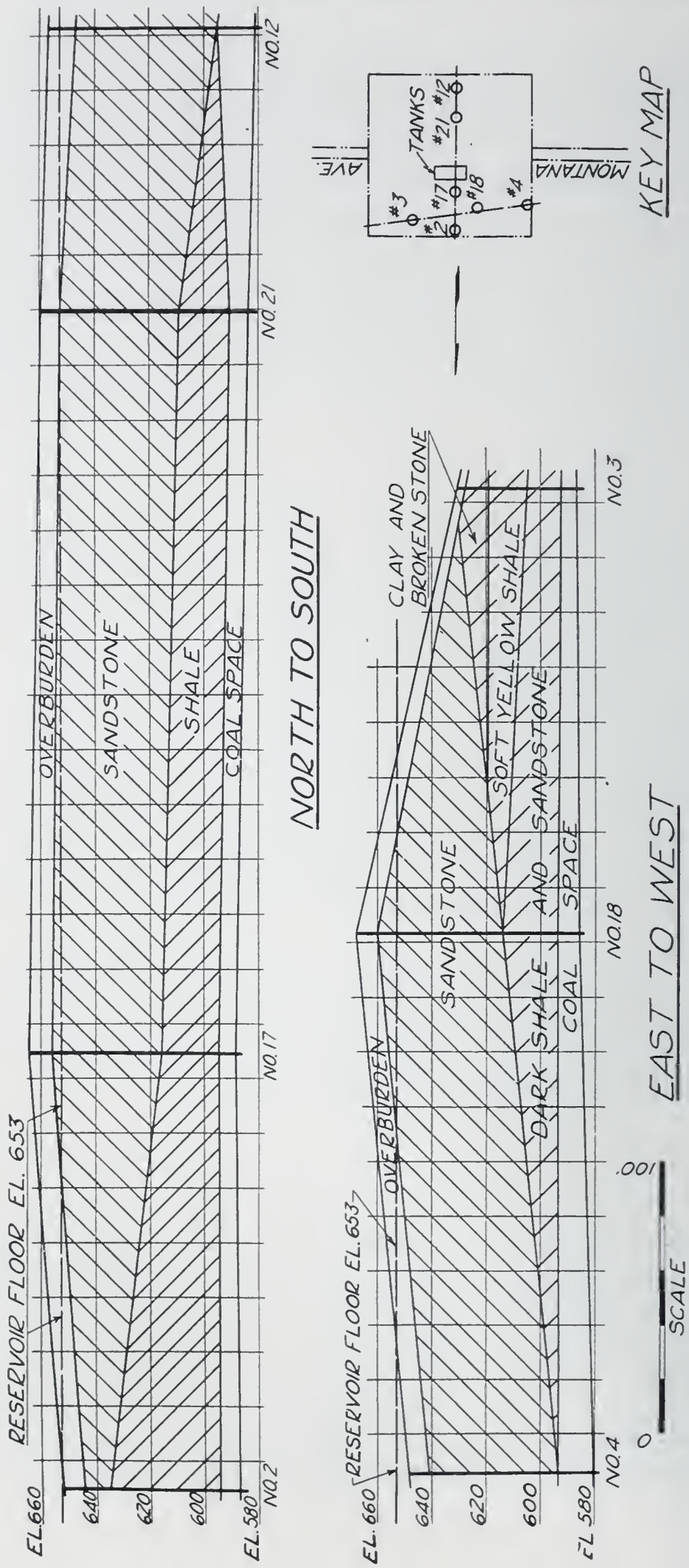

Fig. 1. Geological Formation.

ever, some variations into shale. The borings showed a number of crevices in the sandstone roof, indicating past movement in this rock. There were also cavities in the coal horizon as evidenced by a dropping of the drill occasionally when the coal horizon had been reached. Very little solid coal core was obtained at the coal horizon, but a drive pipe showed rather large quantities of gob—a mixture of fine coal, slate, shale; in general, material which would have been wasted during an operation in which only lump coal was taken from the mine. In one or two cases the core-drill brought up pieces of wood evidently cut from old mine props. Observations of the ground confirmed the indications of the borings, that the coal had been removed to a large extent. The evidence collectively indicated that a large part of the original coal had been removed and that the heavy roof had settled materially with considerable cracking, and that there was in the coal horizon a considerable total of cavities more or less filled by the gob. At the same time there was sufficient stability in the hill to have maintained the Greentree steel tanks with flanged piping connections, for some twenty years without any evidence of distress from settlement.

Development of Theory of Support. During the progress of the borings and due to the above evidences, various methods of treating the site were considered. It was judged impracticable and unnecessary to reopen the mine. Discussion with various mining men indicated that the risk and cost of such operation would be very high, and this idea was rejected.

A method of affording columnar support to reservoir walls by sinking small shafts to strata below the coal was considered. The cost of this procedure through the heavy sandstone for about 60 feet was considered excessive and was subject also to some minor objections structurally. It was thought that if any support were afforded to the walls, a certain measure of support should be supplied for the floor in order to prevent settlement and leakage in this region; also, inasmuch as some embankment had to be placed outside the walls in order to dispose of excavated materials, additional support should be provided for it. Moreover, the placing of columns through the sandstone would hardly prevent shearing stresses or lateral movements in the underlying rock.

A more feasible method appeared to be that of giving additional support at intervals to the existing roof over the site, both under the walls and floor and under the proposed embankment by the use of grouting processes and the additional grouting of the upper stratum of rock in order to fill crevices and thus increase the lateral strength of the rock. This method also promised to be reasonable in cost. While the amount of grout required might be uncertain, some evidence could be obtained on this point experimentally and the cost of drilling could be accurately estimated.

It was felt that the presence of the thick rock layer over the mine was a real asset. Within the reservoir area no increase in load would be effected, and the average increase over the entire area of construction would be only about one ton per square foot. A material increase in the existing margin of stability of the hill would insure the practical safety of the reservoir against any material settlement, and the consequences thereof.

Verification of this view is found in the history of the Herron Hill reservoir. We have had this reservoir in operation for some forty years. It is underlaid at a depth of about eighty feet by a partly mined coal vein. There had been some leakage from this reservoir prior to 1920, at which time a gunite lining was placed in the reservoir. Since this time there had been no appreciable leakage. The hill is apparently in a condition of stability, in spite of a lack of any supporting operations in the coal-mine itself.

Experimental Grouting. When the diamond-drilling job had been finished there were available about 26 holes from the surface to the coal horizon. It was determined to use some of these holes for experimental grouting to see about what absorption of grout could be expected in a systematic program of grouting over the whole hill. This work was first done by the Pennsylvania Drilling Company in connection with its drilling contract, and we are indebted to T. B. Sturges of that Company, and a member of this Society, for certain valuable suggestions. It was later found more advantageous to do some of the experimental work with the city's own forces on account of the difficulties of handling such work under the prescribed routine for the administration of municipal contracts. Five holes were grouted,

a few of these with neat cement, but most of them with 1:3 mortar. It was found necessary to use an agitating grout mixer made by the Union Iron Works Company of Hoboken, N. J., to discharge the sand and cement mortar into the grout pipes without excessive clogging. In order to send the grout supply separately to the mine space and into the rock above the mine the grout pipe was provided with a packer, suggested by Mr. Sturges, which could be set to close the drill hole against the passage of air or grout at any desired point. With this device, the general program was to pack the drill hole about 5 to 10 feet above the top of the coal and to work in as much grout or mortar as possible, under pressure running up to 100 pounds per square inch as a maximum. With this region filled, the packer was loosened and the grout pipe raised to the approximate top of rock when the grouting operation was repeated, the grout or mortar in this case going into crevices in the overlying strata. The following table shows the absorption in various holes:

Hole No.	Cement cubic feet	Sand cubic feet	Total cubic feet
15	162	0	162
3	135	333	468
19	45	130	175
16	12	27	39
20	1	3	4

When the grouting had been pretty well completed a shaft was sunk by city labor, adjoining one of the grouting holes, for the purpose of examining the nature of the coal-mine and observing the effects of grouting. This shaft was sunk without great difficulty, there being no ground water to contend with. In the upper part of the shaft, material was very stable, but as the mine zone was approached the rock became more broken (this rock being mainly shale), and considerable timbering was required to hold the sides. At the region of the mine there had evidently been pronounced settlement. Old mine timbers were found which showed distortion. Numerous cavities were observed, but none of these was very extensive, nor could any of them be followed to a distance greater than four or five feet. Some of the cavities were filled with mortar, or rather with a combination of mortar and gob, a few samples of which were retained

and one of which is now here as an exhibit. You will observe that this material looks like a concrete in which coal and shale form the coarse aggregate. It was evident that the 1:3 mortar, wherever it came into contact with the gob, would effect this kind of combination, chiefly because the coal was of lower specific gravity than the mortar, and would float in the latter until hardening took place. Of course, this combination arose only when mortar was admitted to cavities containing more or less gob. Other empty cavities would get a dose of pure mortar, while still other cavities to which there would be no access from the drill hole would receive nothing.

It was held to be demonstrated as a result of these observations, that the application of cement mortar through a drill hole would, by means of filling empty cavities or by mixing with the old mine wastes, so stiffen up the material adjacent to each drill hole that in effect a columnar support would be provided at this point between the floor of the mine and the roof, this support existing in addition to the previous means of support, whatever the latter might be, and that this additional support would be adequate to insure the support of the roof of the mine.

Formulation of Grouting Contract. The above experimental work justified the preparation of a general contract for grouting this site, and a program for drilling holes was laid out as shown in Fig. 2. It will be observed that this lay-out is so arranged as to concentrate the holes somewhat under the walls of the proposed reservoir, and also to some extent in the northeasterly portion of the hill where there was more shale in the overburden than elsewhere, and where the visible evidence of surface settlement was greatest. The anticipated structure is shown in outline. The reason for the peculiar shape will be discussed later.

Certain particulars of the specification for this contract are perhaps worth attention. In the first place, the contract called for the payment of a definite sum for bringing the contractor's plant on the ground and taking it off, so that if the anticipated program of grouting should not work out as expected and should have to be suspended, there could be no question as to compensation on account of his plant expenditure.

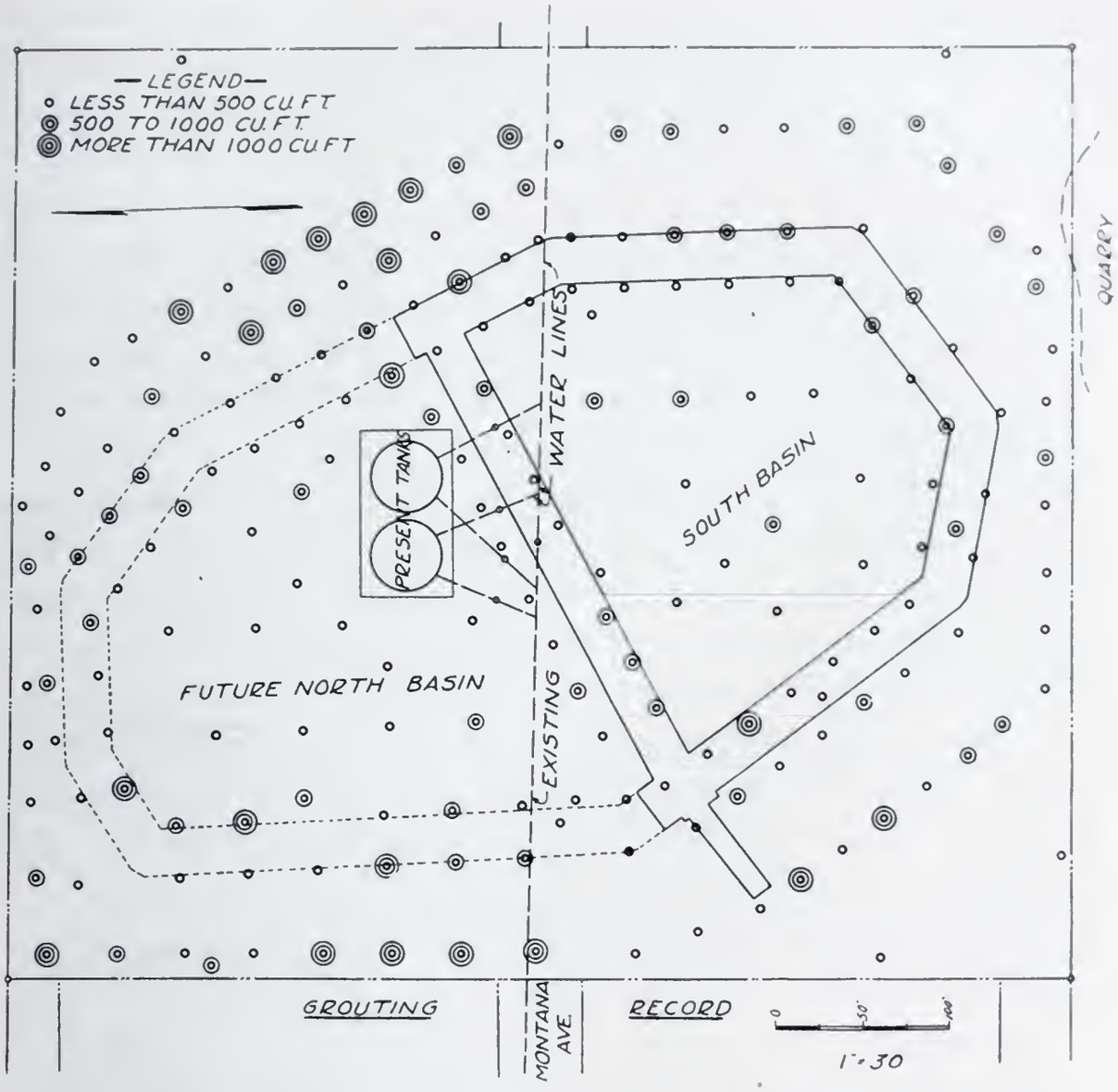

Fig. 2. Lay-Out for Drilling Holes.

Either churn-drill holes or diamond-drill holes were allowed by the specifications. This was done both to secure cheaper drilling and to get relatively large holes in which the packing operations could be conducted with more freedom and in which larger pipes could be used with a more rapid and continuous application of grout or mortar.

In order to cover the matter of payment for the grout applied, it was specified that the normal material to be placed should consist of one cubic foot of cement to three cubic feet of sand, these materials to be measured before going into the grouting machine. Each combination as above stated was to be designated for purpose of payment as four cubic feet; that is, the materials were measured gross before placing. Definite corrections were set up in the contract for departure from this method of proportioning.

The advantages of this specification were that the city would get as low prices as possible and that the contractor would be protected to the greatest possible extent against contingencies of the rather unusual contract.

Description of Grouting Operations. The grouting work was done under contract with the Pitt Construction Company of this city, E. D. Harshbarger, President. Four churn-drill rigs were used for the drilling, this number being required to keep ahead of the packing and grouting operations.

The air for placing grout was furnished by two portable compressors having a combined capacity of about 400 cubic feet of free air per minute. The compressors discharged into a receiving tank with a capacity of about 150 cubic feet. From the receiver the air was delivered to the grout machines through piping and armored hose.

The grout-placing equipment consisted of two Union Iron Works pneumatic grout machines with agitator paddles driven by compressed-air motors. In general, the two grout machines were used separately, but when it became apparent that a hole would require a large amount of grout, both machines were attached to the same grout pipe so as to expedite the filling of the mine space.

In order to promote the maximum travel and penetration of grout through the voids and loose material in the mine space, it was considered essential that the grouting in this region be completed as quickly as possible so as to place pressure upon it while the mass was still plastic. For this reason the space between the drilled holes and the pipe conveying the grout was sealed in the first solid material encountered above the mine space. By packing in this manner, pressure could be placed upon the grout in the mine space without escape of the air through crevices in the upper part of the holes.

After the mine space had been filled so that it would sustain an air pressure of 100 pounds per square inch, the two-inch grout pipe and three-inch packer pipe were removed from the hole and the upper packer was formed by bolting to the top of the six-inch casing, a blank flange containing packing gland for two-inch pipe. The two-inch grout pipe was then lowered through the packing gland and the process of grouting the rock crevices was begun.

Neat cement grout was used for the first few batches for the purpose of securing a greater penetration through the fine waste materials in the mine. If no back-pressure was built up after a few batches had been placed, successive batches were made leaner until the limiting proportion of one bag of cement to three cubic feet of sand was reached. This relatively lean mix was used in most of the grout because of the large voids to be filled, but would not be suitable for filling fine crevices where the sand would have a tendency to strain out and accumulate, finally clogging the entrance to the crevice.

Some interesting evidences of the travel of grout were observed. At several locations, the grout traveled from ten to fifteen feet through crevices and raised the ground at corresponding distances from the hole in which the grout was being placed. In one instance grout placed in the mine space rose through a crevice in an adjacent stone quarry about 45 feet distant from the hole in which the grout was placed. These, and similar observations, together with the quantity of grout that was placed, indicate that the stability of the reservoir foundation was substantially increased by the grouting work.

As would be expected, there was a wide range in the amount of grout required per drill hole. In a few instances, solid rock and coal pillars were penetrated and only enough grout was required to fill the drill holes. At other locations more than one thousand cubic feet of material was placed in a single hole before it was finally filled to refusal under a pressure of 100 pounds per square inch. The largest requirement for any drill hole was 2683 cubic feet of sand and cement. The distribution of the grout is indicated on the grouting plan (Fig. 2). The total amount of grout placed was 91,711 cubic feet, or an average of 475 cubic feet for the 193 holes in which grout was placed.

Design of Reservoir. The location of Brashear reservoir has been hitherto described and the shape is shown in Fig. 3. This roughly oval shape corresponds to the flat top of the hill. Inasmuch as this is the highest hill available for storage on the North Side, and the only one that can supply a considerable part of the district, it was deemed advisable to develop the full storage capacity of the site, which could be done to the extent of about 23,000,000 gallons, by building a reservoir with vertical concrete sides on the indicated lines.

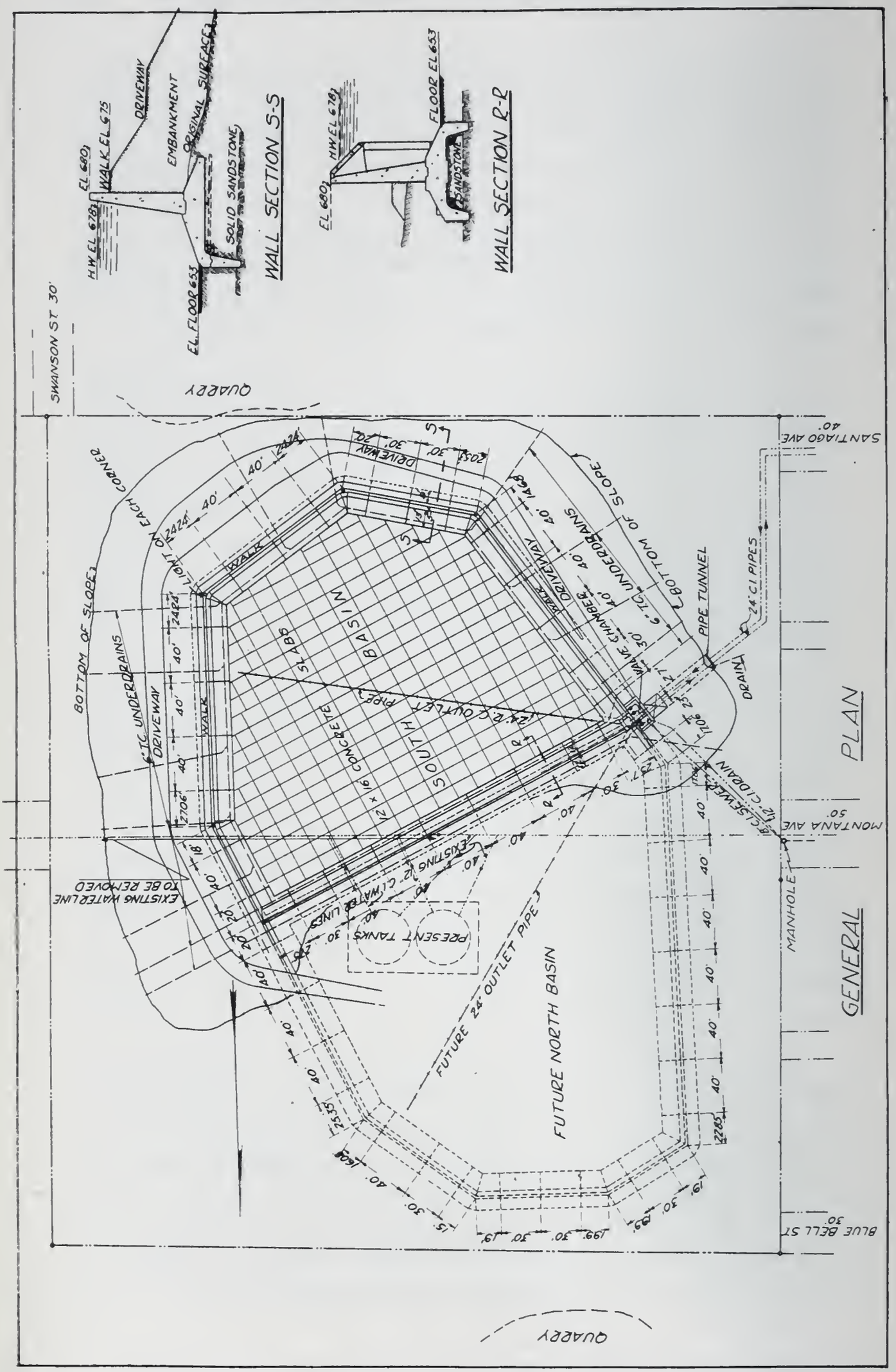

Fig. 3. Brashear Reservoir.

The foundation conditions were favorable to the construction of a type which would resist lateral elements in pressure, the outlines of the reservoir being so located as to keep the wall footings over the solid sandstone of the hill. Where foundation level was above this rock the intermediate space was occupied by broken and disintegrated rock and sand and a little clay with a resisting quality approaching that of hard-pan. In other words, the supporting character of the immediate foundation was very good.

Particular attention was paid to the relative advantages of the T-wall type as actually constructed, as compared with a slab and buttress type in various forms. Decision was finally made in favor of the T-wall for the following considerations (See Fig. 4):

1. Construction is simplified.
2. Fill is easily placed on the outside of the wall.
3. If settlement should occur the heavy vertical wall as well as the footing slab would have sufficient strength to bridge considerable gaps without yielding.
4. Every linear unit of the wall has the capacity to resist water pressure without dependence upon any adjacent units, thus localizing the effects of any settlement.

It will be noted that the "T" section is heavy. The stem was made materially thicker than is required by the ordinary standards of concrete design, in order to lessen the stresses and to promote a long life for the concrete. A move in the same direction was to hold the tensile stresses in the steel on the faces of the concrete adjacent to the water to a value of 10,000 pounds per square inch, so that cracking of concrete would be held to a minimum. For the protection of the bottom of the wall footing against any seepage effects and against undercutting, a cut-off wall was carried down from the footing into the rock at all places where the rock surface was below the bottom of the T-wall. Behind this cut-off was placed a longitudinal drain connected to the toe of the embankment at intervals, there being approximately one such relieving drain per construction unit of the wall. This made it impossible for any upward pressure to occur under the wall or embankment and also afforded certain clues to the existence of any seepage or leakage underneath the wall.

The leakage through the floor would presumably work down through the rock into the old coal-mine. This leakage was checked by using a double concrete floor with complete double layer of membrane waterproofing between the two four-inch layers of concrete, laid in blocks 12 by 16 feet. The bottom concrete layer was reinforced with wire mesh so that if settlement should occur, large cracks would be prevented in the bottom slab, diminishing the probability of rupture of the membrane waterproofing and of large breaks in the floor. Settlement is not anticipated by the speaker, who feels that the measures taken substantially guarantee the reservoir structure against settlement. However, certain precautions in the design against the effects of movement seemed warranted.

Attention should be called to the use of copper-sealed joints between the construction units of the wall and footing and also a copper joint between the footing and the adjoining slab of the floor (Fig. 4). It was felt that this provision was distinctly worth while in order to minimize leakage, especially since the various stages of pumpage head to this reservoir total approximately 750 feet, and the stored water is expensive.

Concrete Proportioning and Mixing. On this job, as well as on the McNaugher reservoir, the proportioning of concrete was specified to be done by weight, the ratio being one sack of 94 pounds of cement to 500 pounds of dry aggregate. This specification required frequent determinations of moisture in the sand and gravel in order to correct the actual mixing by weight to accord with moisture content. The usual proportion was one sack of cement to 185 pounds dry sand and 315 pounds dry gravel. This mixed with about 6½ gallons of total water per sack of cement gave a generally satisfactory mix from the standpoint of workability.

In this connection charts were made indicating the relation of strength tests (which were taken continually throughout the job) to the observed slump of the concrete measured at the time the 6- by 12-inch test cylinders were taken. The average strength of the concrete on this work was high (about 2200 pounds per square inch at seven days, and 3200 pounds per square inch at 28 days). In fact, with reference to the various design stresses used, a very high margin of safety is afforded; but the important point about the diagrams is that,

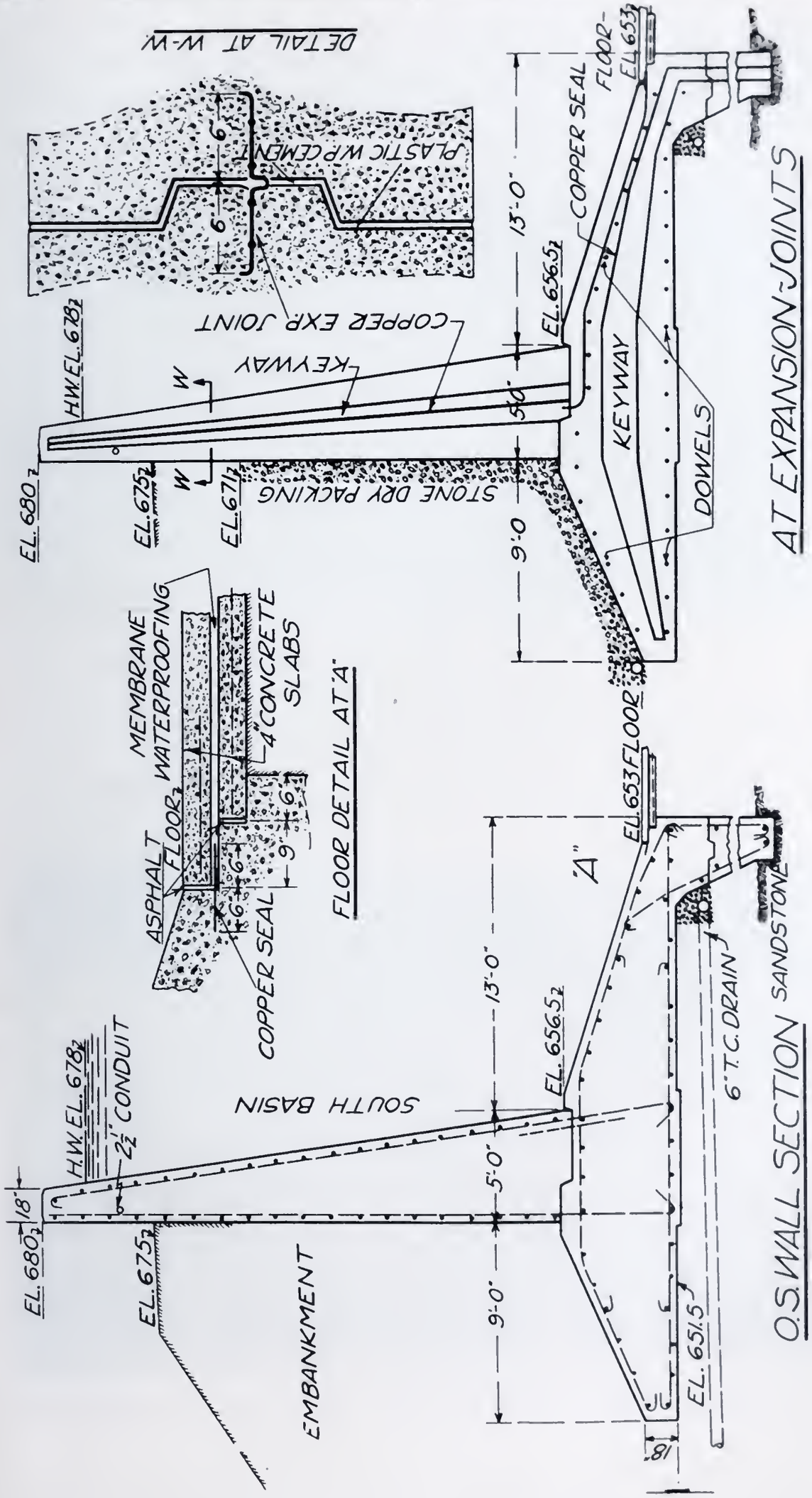

Fig. 4. Wall Construction.

until the slump exceeds 4½ inches, the curves show no material drop in the strength. This is to a certain extent contrary to certain data previously before the profession. The speaker thinks it probable that the presence of water sufficient to increase the slump up to five inches contributes enough in the direction of workability and density to offset whatever deleterious effects may arise from a slight excess of water.

At Brashear reservoir the batching was done by a weighing batcher on the job, this procedure being specified. The batchers were then hauled in trucks to portable mixers of the paving type, which were equipped with suitable open water-tanks with indicating gages and adjustable overflow. The concrete was, in general, handled from the mixer to place by drop-bottom buckets carried by a steam-shovel rigged as a crane. Some of the concrete could be carried from the mixer to place by means of the drop-bottom bucket on a small jib-crane attached to the mixer.

Lessons from Construction. With the use of rich concrete of the proportion mentioned, there seemed to be some tendency to excessive shrinkage in spite of a good deal of care in curing. Some shrinkage

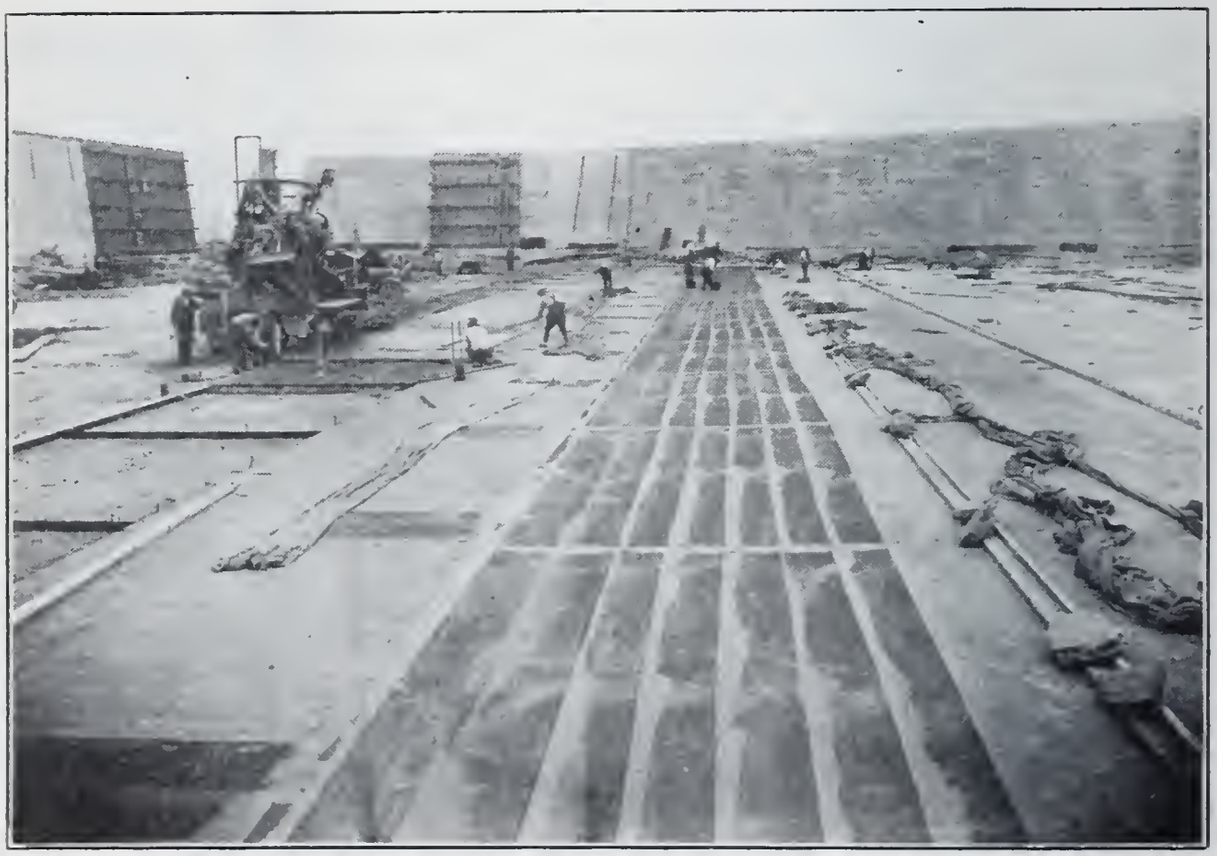

Fig. 5. Brashear Reservoir, Showing Floor Slabs and Waterproofing Slabs.

Fig. 6. Brashear Reservoir, Showing Outlet Pipe.

cracks developed in the walls of this reservoir. When these were first detected, measures were taken to increase the proportion of the temperature of steel by about 60 per cent. for the remaining parts of the work. While this diminished the tendency to crack, it was not a complete preventive. In view of the shrinkage cracks, and also to check any absorption of water by the concrete, it was decided before the end of the job to paint the inner face of the walls with two coats of "Inertol," a coal-tar waterproofing paint. Wherever visible shrinkage cracks appeared, this application was reinforced with a layer of impregnated cotton fabric similar to that used in the membrane waterproofing of the reservoir floor. The side walls by this process were given a uniform black surface inside the reservoir.

Another construction lesson was that where the highest quality of concrete is desired, it is preferable not to place concrete on a slope without forms, as is shown on the base of the T-wall section. The requirement of holding the concrete on a slope tended to reduce the amount of water in the concrete, whereas the heavy reinforcement in the section with the necessity of satisfactory bond tended to increase the quantity of water. The proper adjustment of these two rather

inconsistent requirements created a problem which we should try to avoid in a future job.

Details of the construction are shown in Fig. 5 and 6. The former shows the forms for the walls and the method of constructing floor slabs and waterproofing. Fig. 6 is an interior view of the reservoir when substantially complete, looking from the inlet gate chamber and showing the general proportions of the structure. The pipe in the floor is an outlet pipe with its entrance removed from the inlet so as to secure circulation of the stored water.

The contractor for the reservoir construction was the Bucanelly Construction Company, which has substantially finished the work in an acceptable manner.

McNAUGHER RESERVOIR

The McNaugher reservoir, mentioned heretofore, is considerably smaller than the Brashear reservoir, the capacity of the large and small tanks being 5,500,000 gallons. The borings made on the site showed conditions similar to those at Brashear reservoir, except that the overlying rock was almost exclusively shale, although one or two minor sandstone strata were found lying above the coal horizon. A few cavities were revealed by the dropping of the drill, and the use of sampling irons disclosed similar deposits of gob in the mine. There was no surface indication of settlement and little indication of mining, although the site of an old drift in the immediate vicinity was located and the crop of the vein was observed in a side-hill cut. Considerable stability was evident in the hill, for the Lafayette tanks had been in service just across the street from the selected reservoir site for some thirty years. There was no known history of trouble due to ground movement. The character of the ground is shown by the drill record in Fig. 7, which was taken after grouting surrounding holes.

Type of Reservoir. The peculiarities of this site really dictated the type of reservoir to be constructed. Ground was available on a sort of nose-like promontory, but the width of the hill at the required reservoir level was not great. After a number of studies it was decided that the ground could be utilized to the best advantage and the best location could be obtained by developing a large circular tank of reinforced concrete with a small supplementary tank of the same

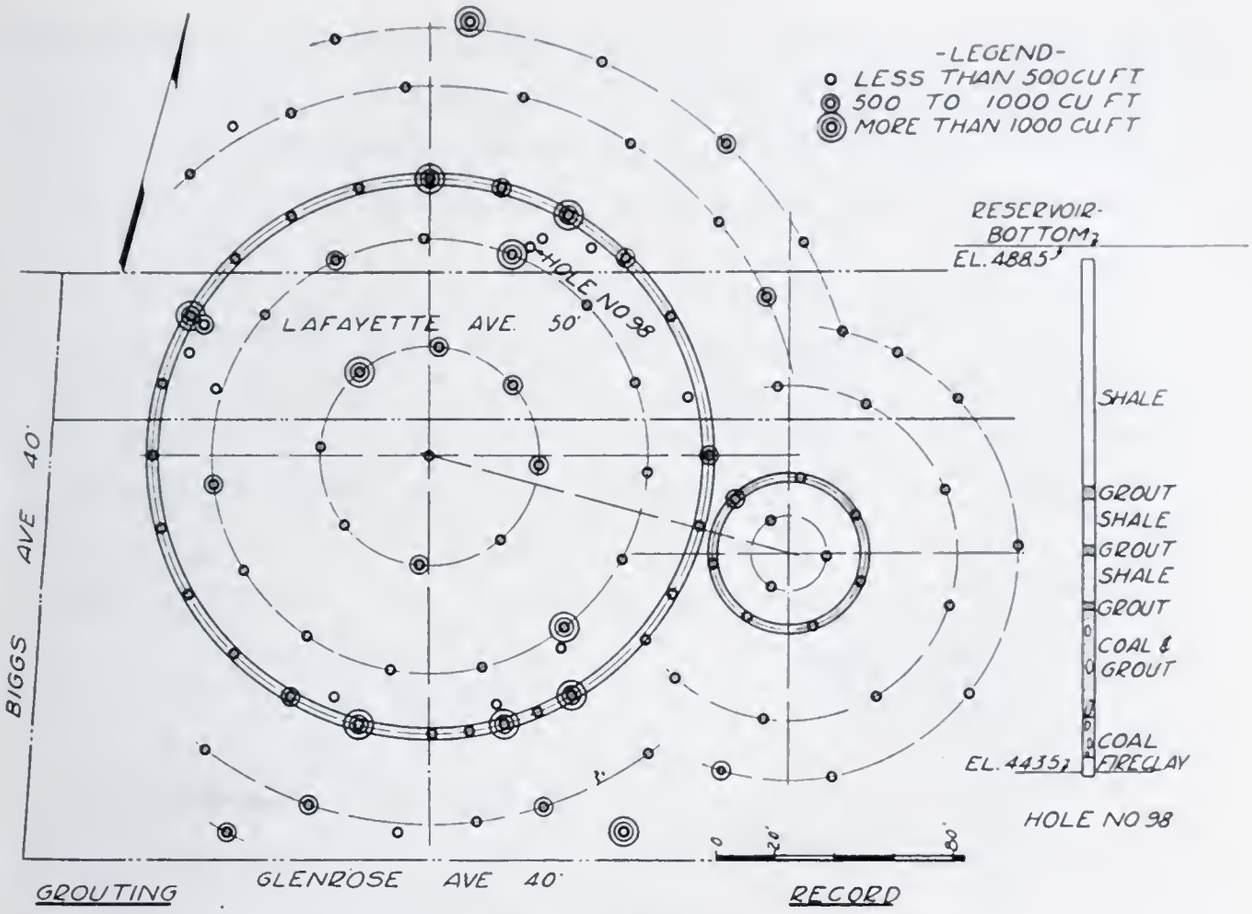

Fig. 7. Drill Record, McNaugher Reservoir.

material which would serve as a pump regulator when the large tank was out of service for any reason. In this case, as in the case of the Brashear reservoir, the dominating consideration was to get as much capacity as the site would permit.

Treatment of Sub-Foundation. The analogous mine conditions led to a subfoundation treatment similar to that at Brashear reservoir. Essentially the same process was followed and about the same kind of results obtained from the operations, which were performed by the same contractor, the Pitt Construction Company, which had the contract for the entire construction of the McNaugher reservoir. On Fig. 7 is shown the location of holes concentrated under the main wall of the reservoir and with more widely spaced holes under the floor of the reservoir and in outer circles designed to prevent settlement from cracks in rock that might extend under the wall. The maximum amount of mortar placed in any hole was 2775 cubic feet, and, following the same classification as for Brashear reservoir, 11 holes, or 10.7 per cent. of the total, exceeded 1000 cubic feet; 17 were between 500 and 1000 cubic feet; and 75, or 72.8 per cent.,

received less than 500 cubic feet per hole. It will be observed that the performance, as far as grout was concerned, was substantially the same at the two sites. Diamond-core-drill holes, drilled after the grouting was done, showed interesting distribution of grout as shown in Fig. 7.

Features of Design. Certain features of the design are worthy of some comment. The construction of the wall of the large tank is shown in Fig. 8. The principal reinforcement is made up of horizontal hoops. In order to insure the concrete against the effects of

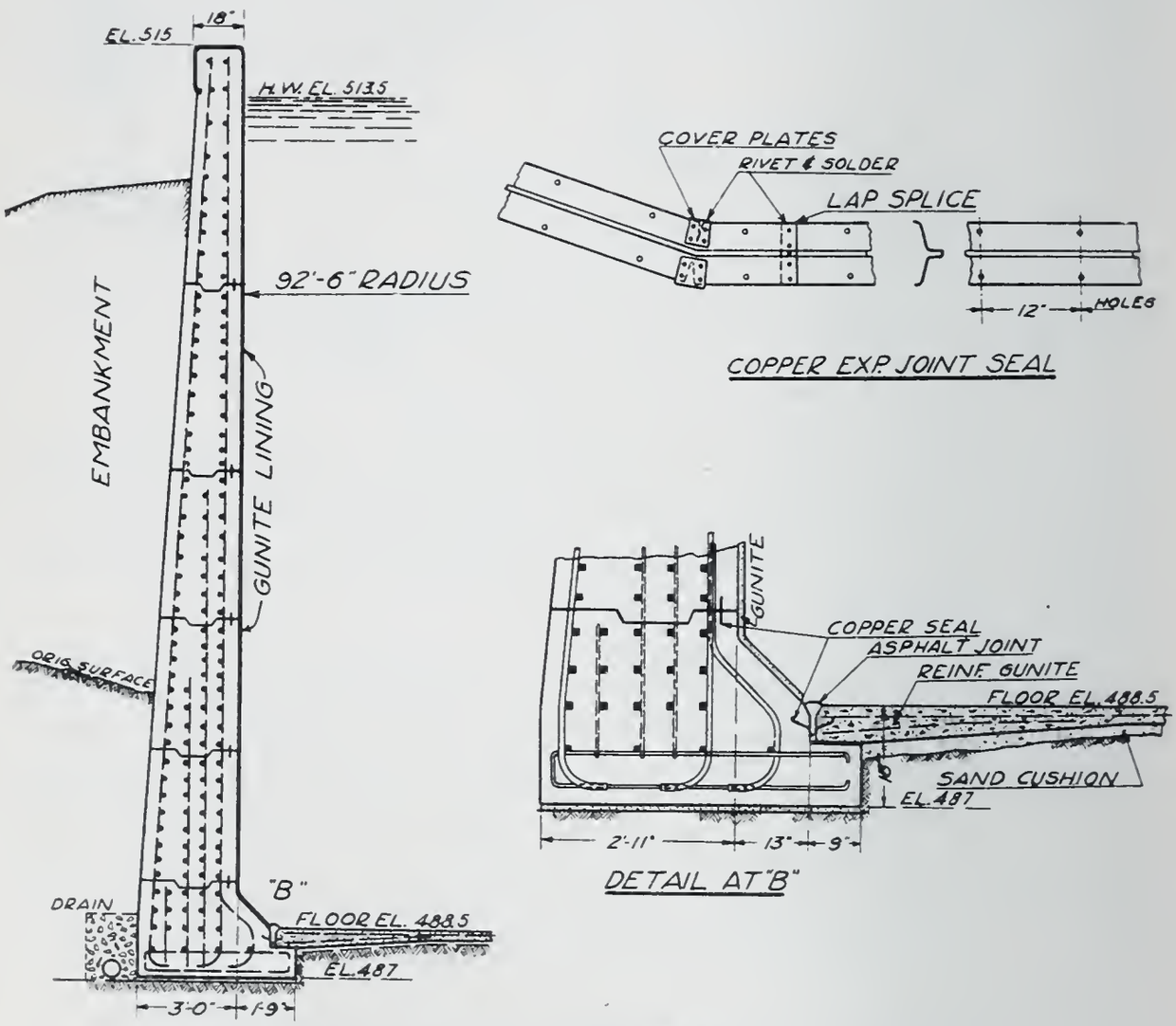

Fig. 8. Wall of Large Tank, McNaugher Reservoir.

cracking, with consequent leakage, the stresses in the hoop steel were kept down to 10,000 pounds per square inch, neglecting any resistance whatever from the earth backing placed around the tanks. This backing was placed as a means of disposing of the extra material which otherwise would have involved an expensive haul, and the pressure

which it might exert, while appreciable in amount, was not regarded as a thing which could be definitely computed and relied upon. Support for the horizontal steel was furnished by welded ladder frames made up of vertical members one inch square and horizontal members ½ inch square.

A departure from usual practice was the specified requirement that the tanks be built with horizontal construction joints. In the case of the large tank, six horizontal lifts were required, each of which had to be poured in a single day, using two mixers. The attempt is usually made to pour such structures as monoliths, and, as far as the observation of the writers goes, these attempts usually fail in some way or another, so that the quality of the concrete job is impaired. By pouring in horizontal sections and maintaining as steep a slope as may be done without bleeding the concrete, the monolithic character of each section is insured, if reasonable care is exercised in the construction. It is essential, however, that sufficient and reliable plant be provided to allow both ends of the section to be poured simultaneously if the wall is of any considerable length.

Notes on Construction. Details of the construction are shown in Fig. 9-11. The method of construction in horizontal rings is shown

Fig. 9. McNaugher Reservoir, Showing Construction in Horizontal Rings.

Fig. 10. McNaugher Reservoir, Showing Gunite Construction of Floors.

in Fig. 9, the fourth ring being poured at the time. The ladders for support of horizontal steel may be seen and also the manner of placing concrete. At the right is a tower over the center monument, used to center the forms. (These forms were required to be within ¼ inch

Fig. 11. McNaugher Reservoir in Service.

of the plan radius.) The guniting of the floor is shown in Fig. 10, the walls having been gunited previously. The apparent vertical joints in the walls are overlaps between successive sections of gunite. Fig. 11 is a view of the reservoir in operation.

Weight proportioning of concrete had been specified on the project as it was on the Brashear job. The uniform quality of concrete obtained is believed to have justified the specification, even though there was at times some difficulty in determining the moisture content of the aggregates with sufficient speed and precision to make entirely adequate corrections to the proportions to compensate for moisture. On this job the batching was done at the docks of the sand and gravel company and the batches hauled to the job. It would have been more satisfactory to have a batching plant on the job, but the quantities of concrete in this case were believed to be insufficient to justify the imposition of this cost on the contractor.

Since the primary purpose of a reservoir is to hold water, it is of interest to record that the two tanks comprising the McNaugher reservoir, with connecting piping, were tested and found to be tight within the limit of a drop of ¼ inch in the water-line in 24 hours.

The Brashear reservoir has been tested under about a nine-foot depth of water with an apparent drop of ¼ inch per 24 hours in the water-line. The task of filling the reservoir from the Greentree pumping station was found to interfere with the plant operation of these small pumps to such an extent that it was decided to delay further testing until piping connections have been completed, so as to permit filling the reservoir by means of the larger new pumping units at the Howard Street pumping station.

Cost. Some general figures of cost may be of interest. On Brashear reservoir the grouting work cost $76,255, of which $29,843 was expended for drilling and plant expenses and $46,412 for the placing of grout or mortar. This operation prepared the entire hilltop for subsequent construction, although only half of the prepared area has been utilized for the reservoir. This half has been built at the contract price of about $200,000, and presumably the second half will be built for a similar amount. It will be observed that the cost of reinforcing the foundation will be about 19 per cent. of the cost of the ultimate reservoir and its pipe connections and control.

At McNaugher reservoir the cost of construction (including drilling and grouting work covered in this case in one contract) was $149,116, of which $6703 was expended for drilling the grout holes and $20,202 for placing the mortar. The total expenditure for sub-foundation work is, therefore, $26,905, which is 22 per cent. of the cost of the reservoir proper and its appurtenances. These percentages are believed to be justifiable amounts expended on foundations for the purpose of insuring the permanence of the structures placed upon them, and are believed to be fully warranted by the public importance of a safe and reliable water-supply.

DISCUSSION

J. T. Campbell:* I should like to ask Mr. Hendrickson a question for my own information. In the grouting construction, the contractor grouted in the six-inch casing, then the grout was to be carried down to the coal area, through an inside drop pipe, and, when that area was filled, the crevices in the rock above were filled. Did the contractor have any trouble in pulling the six-inch casing to uncover the crevices in order to grout them?

G. L. Hendrickson: The six-inch casing was never pulled. Both the two-inch pipe through which the grout was passed and the three-inch pipe which was used to confine the pressure during the first stage of grouting to the lower part of the well, were independent of the six-inch casing so that nothing except the casing was lost by leaving it in place.

J. T. Campbell: I thought that the six-inch casing went down to the coal area.

G. L. Hendrickson: The six-inch casing was used primarily to protect the hole from caving above the rock and was later used to confine the pressure for the last stage of grouting.

J. T. Campbell: Then the lower part of the six-inch casing was never grouted in?

*J. N. Chester Engineers, Pittsburgh.

G. L. HENDRICKSON: Yes, it was grouted in but was never taken out. The six-inch casing was driven only to the top of the rock.

P. J. FREEMAN:* I didn't know the city fellows knew so much about concrete as they do. They certainly did a mighty good job and that was a very interesting paper.

I want to say this, as a matter of record. This is the first time I recall hearing a speaker say anything about waterproofing the construction joints. I don't recall a meeting anywhere with reference to concrete construction during the past few years where that very important thing has even been mentioned. I hope that some time a national society, or this Society, will hold a symposium on how to make construction joints water-tight. Perhaps the speaker to-night has answered the question for us, but let us hope we may have more details as to how this thing was made, how it was installed and later on how it worked. In the first place, where did you get your copper joint? Did you make it? Was it patented?

G. L. HENDRICKSON: It was made on the job.

P. J. FREEMAN: What shape was it?

G. L. HENDRICKSON: We used two types of joint seals. The construction joints between successive lifts of the wall were sealed with strips of copper five inches wide without any crimp or groove for expansion. A different type of seal having a definite provision for movement was used between the base of the wall and the gunite floor.

P. J. FREEMAN: Are you sure it will not crack when in service?

G. L. HENDRICKSON: There is very little probability of movement between successive lifts of the wall because of the heavy vertical steel extending through the joints and, further, because of the ample proportions of the wall section which allowed room for liberal keys in the concrete between lifts. These remarks apply to McNaugher reservoir. The joint between the floor and the wall was designed

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definitely to take care of expansion. It was worked into the shape shown in Fig. 8. The one side of the copper was poured into the wall and the other part into the gunite floor leaving the expansion loop free. The groove was later filled with asphalt.

P. J. Freeman: What kind of asphalt?

G. L. Hendrickson: We used Trinidad asphalt for that purpose. The copper seal strips between successive lifts of the wall were set just inside of the first row of bars, about four inches from the inside face of the wall. They were simply strips of copper and were forced half their depth into the concrete before it had set. These joints were further protected from leakage by gunite one inch in thickness, reinforced by a light welded mesh which was shot on the entire inside face of the reservoir walls.

J. T. Campbell: Did you consider the use of lead instead of copper?

G. L. Hendrickson: Yes, we did. We decided in favor of copper because it is more easily fabricated and kept in shape and position than lead and the copper has a little higher tensile strength.

A. V. Karpov:* First, I wish to congratulate Mr. Riegel and Mr. Hendrickson upon their excellent paper, which represents a real engineering contribution and is in admirable contrast to the sales papers that are so often presented at meetings of different engineering societies.

With reference to the design of large circular concrete reservoirs, it seems that some additional considerations are worth while mentioning.

If the stresses in the reservoir are figured simply as hoop stresses, the figured and actual stresses are in agreement at the upper part of the reservoir. At the lower parts of the reservoir, the disagreement between figured and actual stresses increases and, at the base, a fundamental and total disagreement of figured and actual conditions takes place.

*Designing Engineer, Aluminum Co. of America, Pittsburgh.

The theory of hoop stresses is based on the assumption that the reservoir can expand freely along the whole circumference and this assumption obviously is right only at the unrestrained top and totally wrong at the base. If, in order to keep the figured and actual stresses in better agreement, the base were designed in such a way that under loading conditions, a partial expansion of the base could take place, then every time the reservoir was emptied a total reversal of stresses would take place, and under unfavorable temperature conditions unexpectedly high stresses could develop. It seems that the proper way to design a large cylindrical reservoir is to figure the stresses according to the hoop formula only for elevations above say one-third of the total height of the reservoir. The stresses at the lower one-third should be figured, taking into consideration the restraint at the base. The investigation of the conditions of the reservoir after emptying and under falling temperature conditions, assuming a certain expansion of the base due to previous loading, will probably disclose some significant conclusions unexpected in the usual way of designing such structures.

With reference to the construction joints described in the paper, it would be interesting to know if precautions were taken to make the joints water-tight at the places where the ends of copper strips are put together, or if a plain overlapping of these strips was considered as sufficient. In the expansion joints at the base where the copper strips are buried between layers of the membrane waterproofing, do the authors expect any future trouble due to the hard edges of the copper strips working through the soft layers of the waterproofing membrane?

R. M. Riegel: While the paper may not have brought the question out sufficiently, attention was given to the point raised by Mr. Karpov. Vertical reinforcement was designed at the foot of the circular wall in accordance with the requirements of the handbooks covering this point. Then the layer of sand under the wall was provided to diminish friction on the bottom and permit the bending stresses to relieve themselves, in part. In addition, the passive resistance of the earth backing, affecting nearly the whole height of wall, operates to limit and equalize the expansion of the ring under

stress. The flexible joint at the bottom was designed to harmonize with movement of the ring if it took place.

G. L. HENDRICKSON: In the joint between the wall and the floor, the copper work was made continuously water-tight by making lap-joints between successive pieces of copper, and riveting and soldering all such joints.

P. J. FREEMAN: That is very important in view of the fact that such information is not available as a matter of record; at least I have not been able to find it.

G. L. HENDRICKSON: Between the wall and the floor at Brashear reservoir, we had a joint somewhat different from the usual construction. In general, I don't believe that a metal seal is customary at that point. Reliance is usually placed on the adhesion of the asphalt to the concrete to make the joint water-tight. In this case, however, a copper strip with joints riveted and soldered was incorporated into the concrete footing, leaving about six inches extending out for connection to the floor construction. This extension was later built into the asphalt and the impregnated cotton fabric of the waterproofing layer between the two four-inch concrete slabs of the floor construction. By this means the waterproof membrane of the floor was tied into the concrete walls without leaving a joint through which the water might pass around and under the waterproofing.

The one difficulty encountered with this construction was caused by the expansion and wrinkling of the copper when the hot asphalt was mopped on it. It was necessary to tamp the copper with a light wood tamper a few minutes after mopping, when the copper was partly cooled, so as to force it into contact with the asphalt below. Although this required careful attention, it did not present a difficult problem.

V. R. COVELL:* Was there any danger of the hot copper strip rupturing the soft fabric?

*Chief Engineer, Bureau of Bridges. Department of Public Works, Allegheny County, Pittsburgh.

G. L. HENDRICKSON: We did not experience any difficulty of that kind. After the copper was worked down into position, it stayed there. No break in the copper or waterproofing was observed.

V. R. COVELL: It is sometimes found, with gunite shot downward onto a vertical surface, that there is a tendency to form sand pockets. Did you have any such trouble, or how did you overcome such tendency?

G. L. HENDRICKSON: We have been able to avoid trouble from this source by requiring that the gunite work be done by an experienced contractor using experienced workmen, and by giving the work careful inspection as it was done.

R. H. CAREW:* Can you tell us the thickness of lagging, and the size and spacing of studs and wales, in the panel forms for walls?

G. L. HENDRICKSON: Two by eight vertical studs with six by eight horizontal timbers spaced about four feet six inches apart were used. Two-inch sheathing was used.

R. H. CAREW: What was the diameter of tie-rods, and how were they spaced, and what was the type of coupling or nut on the ends?

G. L. HENDRICKSON: Five-eighth inch tie-rods were used. After the first pour, the horizontal spacing was reduced to about four feet.

R. H. CAREW: Was a chute or "elephant trunk" used in pouring the walls?

G. L. HENDRICKSON: "Elephant trunks" spaced about ten feet apart were used for each stem section.

R. H. CAREW: In pouring the wall, was the rate of pour governed by the time of initial set of the concrete, so the concrete was not permitted to reach certain heights until initial set had taken place a

*Engineer, John F. Casey Co., Pittsburgh.

known distance below; or was the length of wall poured of sufficient length so the concrete did not rise in the forms more than two or three feet per hour?

G. L. HENDRICKSON: After the first pour we found it unnecessary to do that. The washers used for the first pour were not large enough and we did stop concreting twice for a half hour at a time to allow the concrete to set. For subsequent wall sections, washers six inches square were used, and the horizontal spacing of the rods was reduced so that there was no need for slowing up the process of concreting beyond the time required for proper mixing and transporting the concrete to the forms. Pouring a wall section was thus a continuous process except for the noon period of half an hour.

J. W. GUILDAY:* In the design of these reservoirs, why was a gunite floor adopted in one instance and a slab floor in the other?

G. L. HENDRICKSON: In the McNaugher reservoir which was designed first, the floor has a maximum dimension of 185 feet, which was believed to be not too great to get a water-tight sheet of reinforced gunite, with careful work. It provided, under the conditions, a relatively inexpensive water-tight floor in which the location of leakage, if any should develop due to settlement, may be easily determined. The underlying material is largely shale which soon breaks down into clay under the action of water and offers considerable resistance to the passage of water.

In the Brashear reservoir, the free draining nature of the material underlying the floor, and the greater expanse of floor to be covered led to a choice of the double-layer concrete floor with asphalt membrane waterproofing because of the more certain provision for temperature adjustments. Although gunite has been used on much larger areas than the Brashear reservoir floor, many of the cases that have come to my notice either have been laid over a leak-resistant foundation, so that small cracks that might develop would not cause great leakage, or the work was not required to be water-tight. At any rate, it was believed that the construction used offered a greater factor of safety with the existing foundation condition.

*Engineer, Morris Knowles, Inc., Pittsburgh.

J. F. LABOON, *Chairman*:* Then, for the capacities given, roughly the Brashear reservoir cost $20,000 per million gallons capacity as against $30,000 for the other?

G. L. HENDRICKSON: Yes. Several items might be mentioned that tended to increase the unit cost of storage at the McNaugher site. First, an unusually large amount of excavation had to be done in order to use the site for the amount of storage required; second, the site was so fully occupied by the structures that the construction operation was quite congested which, of course, operated against a low price for the work.

Piping connections on the reservoir property were included in the reservoir contract. The piping beyond the property was done under another contract and is not included in the figures given.

J. F. LABOON, *Chairman*: Mr. Riegel mentioned the heavy steel reinforcement on the water side of the wall. Is the other side reinforced for water pressure?

G. L. HENDRICKSON: The north, or future division wall of Brashear reservoir, is reinforced for water pressure from either side. Outside walls are reinforced for water pressure from one side and earth pressure from the other.

J. F. LABOON, *Chairman*: You depend on the earth to balance the water pressure?

G. L. HENDRICKSON: No. Earth pressure was not considered as a helpful item in the design of either reservoir.

J. F. LABOON, *Chairman*: The wall being a cantilever type, I wondered if you really depended upon the earth.

G. L. HENDRICKSON: For water pressure, the reinforcement was on the face of the wall inside the reservoir, the wall being of the cantilever type. The reinforcement for earth pressure was computed as for retaining-wall design and was, of course, smaller.

J. F. LABOON, *Chairman*: Then, the side towards the earth was reinforced for earth pressure when the reservoir was empty?

*J. N. Chester Engineers, Pittsburgh.

G. L. HENDRICKSON: Yes, that is correct.

J. F. LABOON, *Chairman*: There is a tendency to-day to cover filtered water reservoirs, to prevent growths and contamination from outside sources. Is Pittsburgh giving any thought to this matter?

G. L. HENDRICKSON: That has not been done in Pittsburgh. Mr. Lanpher can give you better information than I can as to that. My observations have been that no serious trouble with algæ is experienced. Further reasons for the practice in Pittsburgh are found in the large requirement for storage with the correspondingly large expense, and in the common location of Pittsburgh reservoirs in parks where a water view is believed to be an item of value.

E. E. LANPHER:* While I am no bacteriologist, I think that the agitation for the covering of reservoirs to prevent contamination has been unduly stressed, particularly in the Pittsburgh district where stored waters seldom contain algæ growths.

In regard to the so-called bird nuisance, this section is not visited by gulls, and the resident birds, such as the robin and sparrow, do not fly over an expanse of water, such as a reservoir, if it is possible to fly around it. We do have a rare visitation of migrant ducks or geese; there were 147 white geese in one such flock. They would not remain more than a day even if undisturbed, and it is an easy matter to drive them from the reservoirs.

J. F. LABOON, *Chairman*: In Cincinnati, and I believe in St. Louis, covered reservoirs are being considered, and in California and elsewhere they are covering reservoirs even though surface water is stored in which you would not expect bacterial growth. I know you are right about the rivers here.

E. E. LANPHER: Inasmuch as continuous examinations have failed to show serious secondary bacterial growth in our reservoirs, the covering of the reservoirs in my opinion, would be an unwarranted expense, and it would be against good policy to cover the only vistas of attractive clear water that we possess. Even if the general public

*Managing Engineer, Bureau of Water, City of Pittsburgh, Pittsburgh.

could be excluded from the top of a covered reservoir, there remains the possibility of contamination from the workmen. I would, however, be in favor of placing the fences, wherever possible, ten or fifteen feet back from the curbs of open reservoirs.

J. F. LABOON, *Chairman*: We don't have any suicides in our reservoirs?

E. E. LANPHER: In the matter of suicides in our reservoirs, we have had, during my 25 years with the Pittsburgh Bureau of Water, three such cases and one attempt. One suicide was in Highland No. 2 reservoir; two suicides and one attempt were in Bedford reservoir. In such cases we promptly shut off the water where possible, and treat the water with chlorin. The chlorin application, while seldom if ever necessary in such cases, does no harm, is certainly on the side of safety, and promotes confidence on the part of the public.

If a man is bent on committing suicide in a reservoir, he is going to go down one of the many vent holes of a covered reservoir just as surely as he would climb the fence and go down the slope of an open reservoir. The reasoning of a man about to commit suicide is beyond my comprehension. The one case at Highland No. 2 reservoir illustrates this. The back yard of his home near Sewickley extended to the Ohio River; he used all of his available money to reach down-town Pittsburgh, then walked nearly six miles to drown himself in one of our reservoirs, when he had a choice of the Monongahela, Allegheny and Ohio rivers, much more conveniently located.

I think that the suicide matter is also unduly stressed, and I do not agree that the covered reservoir would eliminate it; certainly in the rare cases that we have to meet, the victim can be much more quickly removed from the open reservoir than from the covered one.

W. C. HAWLEY:* I agree with Mr. Lanpher that the matter of pollution in open reservoirs is too highly stressed. We have four open reservoirs, three supplied by gravity from reservoir No. 1. We are analyzing the water in different parts of our distibution system before and after the water passes through these reservoirs and we find

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nothing to indicate any increased pollution. There will naturally be a small increase in the growth of ordinary water-borne bacteria but there is no evidence of increased pollution as would be indicated by the presence of the colon bacillus.

J. F. LABOON, *Chairman*: There is a recent record of a case either in San Francisco or Los Angeles where gulls carried things over the reservoir and caused serious pollution. The authorities found a way to prevent the gulls from flying over the reservoir and resting on the walls by stretching fine wires across, and as they flew across, the noise created by their wings and the air on the wires scared them off.

E. E. LANPHER: Those cases were near the ocean where gulls are a great nuisance.

J. F. LABOON, *Chairman*: Yes. Talking about concrete, there came to my attention the other day a reservoir of about the size of the McNaugher reservoir here in Pittsburgh, designed by a consulting engineer of reputation who made the wall of ring type about five feet thick at the bottom and then stepped it back until it was three feet thick at the top, but they were never able to fill this reservoir more than half full and even then had considerable leakage. We were called into the case and found that you could pick out the concrete in any part of the wall by hand; it looked good but it was very poor concrete. Upon making an examination of the reinforcing steel in the wall I found it had only a 12-inch lap for 1¼-inch bars. It was a rather fine looking job at a distance but certainly of poor character.

It might be of interest to relate how a similar situation was handled in another city—a situation similar to this coal-mine development under the two reservoirs just described. At Wheeling, W. Va., I observed that there were workings of an old mine located some eighty or ninety feet below the surface of the site of the proposed reservoir which was to be built by that city, and after a study of the situation I found a history somewhat parallel to that described by Mr. Riegel. No one remembered this mine as it had been worked some fifty or sixty years before. It was a drift mine and had about forty or fifty feet of sandstone rock over the top of the coal. Although we could see some weak points in the situation, after due consideration it was decided that inasmuch as the site was located at the head

of a valley and on a hillside we would adopt steel reservoir tanks, and therefore we benched out of the slopes sufficient area to place five 1,000,000-gallon covered reservoir tanks. Our theory was that if there was any movement of the substrata, the reservoir tanks would be able to withstand a goodly amount of distortion without any serious consequences, whereas a concrete structure might fail. Furthermore, the adaptation of a concrete reservoir to a valley where you would need a 40-foot wall on one end, running out to a point at the other end, would be rather difficult to build at any cost, and I think the economics of the question were well founded, inasmuch as we were able to build these reservoirs for a unit cost of $25,000 per million gallons, and this involved some 35,000 cubic yards of excavation. At the same time we were able to bench out sufficient area to provide for doubling the capacity that was installed.

R. M. Riegel: In both reservoirs, in the preliminary stages of design, we considered the use of steel tanks; but, as I tried to state, we were faced with the need for all the storage we could get, and we found that with any steel tank scheme we worked out on either site, we were sacrificing so much space that the storage realized would be much less, with tanks than with other schemes. We felt it was a wiser procedure to utilize all the space we could, even if it meant going to another type of construction. The point is, we considered in this case the same alternative as you did, but it didn't seem to work out so advantageously.

E. E. Lanpher: There are two points that I would like to add. There is no hill on the North Side above 1000 feet elevation, suitable for reservoir purposes, that has not been undermined.

In regard to the Brashear site, we are convinced that the mining operations were carried on at least ninety years ago. Lifelong residents over eighty years of age, claimed that the coal had not been removed. Allegheny originally purchased the site with this understanding. However, the test pit and drill holes gave evidence that the coal had been removed to an extent quite unusual in such old operations.

The test pit, about 45 feet deep, showed conditions in the mine very well. The roof of the mine and all the overburden had fallen, probably many years ago, so that there was little mine space remaining. It was impossible to reach the length of one's arm into any of

the spaces, or holes, without encountering rock or shale. From the pit it was impossible to see even the reflection of a light in a drill hole only 18 feet away.

From a study of this pit, and particularly of the rock structure, I am of the opinion that the mine pillars crushed long before Greentree tanks and the United States Geological Survey monument were placed on the site.

C. N. HAGGART:* During the course of your grouting operations, if you found a hole requiring a large amount of grout, did you slow up on it, or did you force it in as fast as the ground would take it?

G. L. HENDRICKSON: When an open space in the mine was encountered, we attempted to fill it. If a hole gave indication of requiring a large amount of grout, we attached two grout machines to it and operated them together so as to increase the probability of filling the space while the mortar was still in a plastic condition. If grout was escaping to the surface, as happened in two or three instances, it was necessary to delay grouting until the avenue of escape was sealed by the hardened mortar.

JOHN M. RICE:† We have heard a very interesting paper here this evening. I have had a lot to do with reservoir construction and I want to congratulate both of the authors on giving us a paper which describes what is a rather unique way of solving a very difficult problem. I think that most engineers, confronted with the question of building a reservoir of this type over a coal-mine, would hesitate to do it.

It seems to me that the authors have gone into the matter very thoroughly, and I believe they have successfully solved a problem which applies in all places where coal-mining operations have been carried on at all extensively. I am very much impressed with the precautions they have taken to make both of these reservoirs tight. I don't say that they were all needed, but I believe they were a wise and proper expenditure of the public's money, because any of us who have to do with the storage of water in concrete structures know that it is a very treacherous and difficult matter.

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†Consulting Engineer, Pittsburgh.

HIGHWAY CONSTRUCTION*

By Samuel Eckels†

To understand and appreciate the public road and highway situation in Pennsylvania to-day, it is necessary to go into the history of highway development in this state and the manner in which the highway system was originally created and laid out.

In the early Colonial days the matter of the up-keep and proper maintenance of public roads was one of serious concern, as was evidenced by the numerous petitions for road betterment presented to the Colonial Council. The enactment of various laws, and the adoption of resolutions providing for road maintenance can be found in the early Colonial records. These several laws were consolidated into the general road law of March 21, 1772, which also provided for the election, each year, of the supervisors in their respective districts. The provisions of this act, with amendments, were continued until the enactment of the law of June 13, 1836, this latter act including the principal provisions of the act of 1772. The act of 1836 is the basic law under which proceedings for the opening of public roads are instituted to-day.

The insistent call of both the West and the North resulted in the establishing of paths and trails from which were developed the early roads and highways of the Commonwealth. The West and the North demanded commercial supplies from the centers of distribution, and in turn these centers called for a continuous supply of agricultural and food products. These factors working in unison demanded better roads and highways over which supplies could be more easily and economically transported. This demand shortly after the close of the Revolutionary War called into existence the turnpike or toll-road system, which, beginning with the Philadelphia and Lancaster turnpike construction, under the provisions of the act of April 9, 1792, extended to all sections of the state, so that by 1831 it was reported that 2500 miles of toll roads were being operated.

At the time of organizing the State Highway Department in 1903 there were being operated 1101 miles of toll roads. The Commonwealth invested in the construction of the toll-road system up-

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wards of $2,000,000. Appropriations were made in an amount equal to, or exceeding, the amount contributed to the turnpike system for the opening and improving of "state roads" authorized by legislative enactment. The turnpike or toll road had its uses and served its time and purpose, being a vast improvement over the mud or corduroy road.

After traffic increased, local communities, with but few exceptions, were unable to cope with the problem of maintaining the public roads and they were permitted to become in such condition as to make them dangerous and unsafe for travel. How to improve these conditions was a question that agitated the public mind for a number of years and, in order that the public might be better informed as to the value of good roads, in November 1889 a prize was offered by the co-operation of interested citizens of Philadelphia and the University of Pennsylvania for the best paper upon construction and maintenance of common roads. This had a stimulating effect and as a result many townships in the vicinity of Philadelphia constructed several miles of Telford macadam road.

Under the act of June 12, 1893, taxpayers of townships and road districts were enabled to contract for making the roads at their own expense, paying salaries of township or road-district officials, thereby preventing the levying and collection of a road tax. There are 25 townships working under this act at the present time.

Under the act of June 26, 1895, commonly known as the Flinn Act, there was organized a county road system in Allegheny County, and afterwards in other counties, until there are now 15 counties working under that act by reason of their maintaining abandoned or condemned toll roads or other roads established as county roads under the provisions of this act.

As methods for the transporting of supplies and passenger conveyances changed, a demand for better roads became persistent throughout the state. A potential voice in the demand was that of the bicycle rider, so strong that the act of April 1899 was passed providing for the appointing of a Side Path Commission to have general supervision of the maintenance of sidewalks along the highways of the townships of this Commonwealth, for the use of bicyclists and pedestrians, the bicycle riders, however, to have the right-of-way. A tax not to exceed $1 a year per wheel was to be levied and collected by the county com-

missioners on each bicycle to pay for the cost of the construction and maintenance of such walks, the fund so raised to be called the sidewalk fund.

The demand of the bicycle rider was reinforced by a still louder demand by the automobilist, and as these demands became continuous, together with the fact that local authorities having charge of the up-keep of public roads were unable to provide the funds for their maintenance and repair, it was deemed advisable to establish a State Highway Department in 1903.

The bill to establish the State Highway Department had rough going; it was held up in the Public Roads Committee and was about to be reported with a negative recommendation had it not been for the quiet, yet persistent, effort of Governor Samuel W. Pennypacker, who insisted upon its reconsideration and passage.

Upon the approval of the act of April 15, 1903, commonly known as the Roberts Act, Governor Pennypacker appointed a commissioner to organize the Department of Highways. This act did create a Highway Department, but authorized the state to co-operate with local authorities on a state-aid basis, the county commissioners petitioning for the improvement of township roads, the state paying two-thirds of the cost of construction, and the county and township dividing one-third of the cost between them. The counties and townships were to maintain the highways after the improvement and the state was to pay one-half of the maintenance cost. To carry out the provisions of this act the Legislature appropriated the sum of $6,500,000 to cover a period of six years.

The work of reconstructing township roads under this act of 1903 was inaugurated on April 13, 1904, when Governor Pennypacker broke ground for Application No. 1, at Shamokin Dam, Snyder County.

In 1905 the Legislature re-enacted the law of 1903 and provided for the appointment of additional assistants. The surveys and plans were to be made by the Department, the state was to pay 75 per cent. of the cost of construction, and the county and township 25 per cent. between them.

The year of 1905 was a red letter year in the annals of this Department, as during this session the Legislature passed four momentous laws that had a direct bearing on the future development of

the Department and the improvement of public roads and highways —the re-enacted state highway law; the act relating to township supervisors; the motor vehicle law, which became effective January 1, 1906; and the act relating to the National or Cumberland Road.

The National Road from Cumberland, Md., to Wheeling, W. Va. had been constructed by the national government under an act of Congress, approved by President Thomas Jefferson in 1806. The Commonwealth in 1835 assumed the care and maintenance of this national road within the borders of Pennsylvania, erected toll houses, and collected toll to pay for the management and maintenance of the road. This system continued until 1905, when by act of Legislature tolls were abolished. The maintenance of the road was transferred to the Highway Department, and the National Pike thus became the first state highway entirely under the jurisdiction of the Department of Highways.

The motor vehicle law, which became effective on January 1, 1906, was the first law giving the state control of the licensing of motor vehicles. During the year 1906, 10,954 licenses were issued, with a total revenue of $42,460. Compare this with the year 1927, when approximately 1,600,000 licenses were issued, and the fees collected amounted to approximately $26,000,000.

The Sproul Act, passed by the Legislature in 1911 and approved by Governor Tener on May 31 of that year, provided for the complete reorganization of the State Highway Department along the general lines under which it now operates. It established a system of state highways to be taken over, maintained, and constructed at the expense of the Commonwealth. The Sproul Act of 1911 and its supplements of 1913 designated 8835 miles of township roads as state highways to be marked, built, rebuilt, constructed, repaired, and maintained at the expense of the Commonwealth. This mileage has, by subsequent legislation, been increased to 12,750 miles. The system of state-aid was retained, but the percentage of aid was adjusted so that costs were divided equally between the Department and the local authorities. This has been changed by recent legislation to provide for construction on a state-aid basis in counties of the seventh and eighth classes, with the state paying for 65 per cent. of the cost of construction and the local authorities 35 per cent.

At the present time there are 580 miles of state-aid highways off the highway system, making a total of 13,330 miles of state highways and state-aid highways under the jurisdiction of the Department.

It should be borne in mind that the work of the Department from 1911 (at the inception of the highway system) to 1919 was limited by a lack of sufficient revenue, which prevented the appropriation of ample funds to enable the Department to carry out the provisions of the act as expeditiously as was demanded by the citizens of the Commonwealth. It was a period of preparation for the time when there would be funds available for an era of construction activity.

On January 1, 1919, only 3000 miles of the state highway and state-aid highway system were hard surfaced, approximately 5800 miles being entirely unimproved.

From the primitive organization under the acts of 1911 and 1915 has been evolved the organization of to-day. The money derived from two bond issues of $50,000,000 each, supplementing other funds, has enabled the Department to construct about 6000 miles of hard-surfaced roads on the state highway and state-aid highway systems since 1919, as the total improved mileage of the Department is 8800 miles. In the construction of this mileage of hard-surfaced roads, in the past nine years, the Department has by a rigid location policy eliminated practically 210 miles of unnecessary travel distance by relocating these highways. By shortening the system to this extent the traveling public has been saved approximately $10,000,000 a year in operating costs.

At the time of the establishment of the state highway system in 1911, 521 miles of this system traversed turnpikes or toll roads and subsequent Legislatures have added toll roads to the system since that time. Under the provisions of these acts the Department eliminated tolls from all of these turnpike roads, except one road added by the Legislature of 1927. This was accomplished with the co-operation of the several counties through which these turnpikes passed, the counties in nearly all cases contributing 50 per cent. of the purchase price.

This completes the history of the early development of Pennsylvania's highway system from an endless maze of unimproved roads as existed in 1903, to a well-developed system of primary and secondary routes, comprising some 12,750 miles of highways. The primary system was laid out early in the Sproul administration and consisted of

the more direct state highways connecting county seats, and as such has remained practically unchanged to date. This primary system of 4000 miles has either been entirely paved, or contracts are under way which will complete this construction in the very near future.

When the construction was under way, from the proceeds of the first bond issue, the selection of the type of pavement to be constructed was largely a matter of personal judgment with the Department engineers, each section being considered on its own individual merit. It was soon realized that in order to design the pavements on this transportation system properly and intelligently, traffic studies were necessary, and thus in 1924 a highway transport survey was made by the Department in co-operation with the United States Bureau of Public Roads. This traffic information was needed as a guide so that the money could be wisely spent in providing for the future traffic needs. The purpose of this survey was nothing more or less than an investigation with a view to determining all the factors affecting the existing and estimated future transportation requirements of a highway system. It involved a study of the existing traffic on the highway system and the characteristics of the sections of the state traversed by, and tributary to, the highways with respect to the industries and the density of population. The study included, among other things:

1. An economic and industrial study of the state, embracing the occupations of the population in different regions.

2. The areas of various industries, such as manufacturing, mining, agriculture, and lumbering.

3. The amount of production from the various pursuits in different sections of the state, indicating the major changes in production within the past several decades.

4. The origin, destination, and percentage of the production of the state and from without the state transported over the highways.

5. The amounts of the various commodities transported.

6. The quantity and characteristics of the passenger traffic, including the origin and destination of the travel, and whether business or recreational.

These are just a few of the fundamental considerations embraced in the Pennsylvania Highway Transport Survey, all of which were factors to be considered in determining the earning capacity, not only

of the entire highway system, but of the different routes and sections of highways.

This study and the analysis made in connection with it have given the Department data from which to determine the necessary carrying capacity, width of pavement, and ultimate width of right of way to permit the widening of the pavements to provide for future traffic. From the facts developed by the survey it is possible to forecast accurately traffic conditions on any section of the highway system for many years in the future, and this study is the basis upon which the Department selects the type and character of pavement to be constructed, and the logical location to undertake construction.

In the development and construction of our state highway system, the Department has classified highways into three general classes:

1. Highways carrying, when improved, an average present-day traffic of 3000 or more vehicles.

2. Highways carrying an average of present-day traffic of less than 3000 and more than 500 vehicles a day on primary routes, or more than 1000 vehicles a day on other highways, when improved.

3. Highways carrying less present-day traffic than indicated for highways in Class 2.

In order that all highway projects may be developed on the basis of sound engineering principles with due consideration of traffic development in the future, the following policies relative to width, grades, and alinement have been established by the Department:

Class 1 Highways. The Department anticipates that this class of highways will require more than two 10-foot paved lanes, and if practicable the shoulders should be developed 10 feet in width on either side. High curbs shall not be placed on a highway which will not provide for at least three travel lanes plus minimum eight-foot parking lanes on either side. The width of parapets on bridges or structures shall be not less than the width of graded roadway, except bridges more than 45 feet in length. On this class of highway a sincere effort shall be made to hold seven per cent. as a maximum grade, except on structures for elimination of grade crossings, where the maximum grade shall be five per cent. The degree of curvature shall be held to four degrees or less and an explanation shall be given for the necessity of any curve of a greater degree. On structures for elimination of grade crossings the maximum curvature shall be six

degrees. On all Class 1 highways the sight distance shall not be less than 400 feet.

Class 2 Highways. The width of these highways shall be not less than two nine-foot or two 10-foot traffic lanes as requested, and if practicable the graded width of the shoulders shall be from eight to 10 feet in width on either side. High curbs shall not be constructed on such highways closer than will permit two moving traffic lanes and two parking lanes not less than eight feet in width. The width of parapets on bridges or structures shall not be less than the width of graded roadway, except bridges more than 45 feet in length. On this class of highway a sincere effort shall be made to hold the maximum grade to seven per cent., but an eight per cent. grade may be used without explanation. On grade-crossing eliminations the maximum grade shall be five per cent. The degree of curvature shall be held to four degrees or less and an explanation shall be given for the necessity of any curve of a greater degree. On grade-crossing elimination the maximum curvature shall be six degrees. On all Class 2 highways the sight distance shall not be less than 400 feet.

Class 3 Highways. The width of these highways shall be not less than two nine-foot traffic lanes, and the graded width of shoulders shall be from five to eight feet on either side, as conditions warrant. The width of structures between parapets shall be the full width of the graded roadway, if practicable, and in no case less than 22 feet between wheel guards or curbs. A sincere effort shall be made to hold the grades as low as economically practicable, with due consideration to the importance of the highway when ultimately developed throughout its length. On grade-crossing eliminations the maximum grade shall be six per cent. The curvature shall be kept to six degrees or less, and on grade-crossing elimination the maximum curvature shall be eight degrees. Sight distance shall not be less than 300 feet.

On all classes of highways an effort shall be made to avoid the combination of maximum curvature and grade. Due consideration must be given to the ultimate necessity for by-passing congested, built-up regions, particularly on Class 1 and Class 2 highways.

In line with these policies the Department in replacing the important sections of the Lincoln and William Penn highways is constructing not less than 20 feet of pavement, and in the urban sections

near Pittsburgh and Philadelphia this width is being extended to 30 feet or more.

The selection of type is made upon the basis of sound engineering principles, involving the study of present and future traffic, the amount and character of truck traffic, the availability of material, and the cost of maintenance. All of these factors are given due consideration on every project before the type is finally selected.

A large majority of the rigid pavements constructed for the past eight years have been various types of reinforced concrete pavements. The general design has been changed from time to time and the Department is now using a thickened edge pavement, adopted with variations, as a result of the Bates road tests, with a longitudinal center joint and either marginal bar, bar mat, or special fabric reinforcement. The prevalent type of construction is a pavement nine inches in thickness on the edges and seven inches in thickness in the center, these dimensions being increased to 10 and eight inches, respectively, in the urban sections where a large portion of the traffic is composed of heavy trucks.

The Department now has under construction a large mileage of vitrified brick pavement on a concrete base, extending on the Steubenville Pike from the Allegheny County line west of North Star to the Ohio state line.

All of the Department's construction work has been done under a very rigid set of specifications, which have been revised and changed from year to year, but which are practically the same as those that were first developed 10 years ago. Rigid adherence to these specifications has resulted in the construction of the finest quality of pavements in which every part of the material is carefully scrutinized and tested and the construction undertaken under carefully prescribed methods and standards.

The 4500 miles of unimproved highways now on the state highway system are almost entirely on the secondary system of highways, and it is for the completion of this mileage that the Department is using all the money available for new construction. While additions to the highway system are made by legislative action, it is the desire and recommendation of the Department that no additions be made to it until the unpaved mileage is either completed or money is available to assure its completion.

In the time available it is impossible to go into detail regarding the ramifications of the Department's work and the construction of the highway system. During 1927 and 1928 the Department constructed 1100 miles of durable pavements at a total cost of approximately $50,000,000. This, however, constitutes only a part of the duties and responsibilities of the Department. The maintenance of the highway system, the purchase and operation of equipment, the administration and engineering work in connection with both the construction and maintenance activities, the administration of the Bureau of Motor Vehicles and the Highway Patrol involve the expenditure of more than $23,000,000 each year.

The highway business involving the expenditure of more than $50,000,000 each year is one of the largest of its kind anywhere, and the expenditures are made under the policy of securing the maximum value for every dollar expended.

DISCUSSION

J. T. Campbell:* Is it the intention of the Department to superelevate the curves on main highways which have not been taken care of in that manner?

Samuel Eckels: We realize, as well as the traveling public, that the first roads were very poorly designed. As fast as possible, where conditions permit and maintenance charges require, we are replacing these sections of highways, especially those which do not have superelevation. If we had sufficient funds, we would replace all those curves that are not properly superelevated.

P. J. Freeman:† Mr. Eckels mentioned the saving by cutting off curves. Many people look on such figures with a great deal of skepticism as if they were something very hard to determine. As a matter of fact, everyone knows about what it costs to operate an automobile per mile. All you have to do is to count the number of vehicles going over a road each day and calculate how much you can afford to spend for cutting off a given curve. The shorter road will undoubt-

*J. N. Chester Engineers, Pittsburgh.
†Bureau of Tests and Specifications, Allegheny County, Pittsburgh.

edly carry more traffic than the one with the curve, so your calculations will be on the safe side.

Traffic surveys establish the fact that the great majority of vehicles are local and that they originate within fifty miles of the center of population of the particular point where you are taking your traffic count; it is, therefore, the local people who get the benefit of the cut-off you are making.

These same figures will apply to the calculating of permissible first cost of a pavement. Traffic studies have shown that our Liberty tunnels carry approximately 22,500 vehicles in 18 hours. You can easily figure how much we could afford to pay to shorten an approach to the tunnels or pay for a high type of pavement on the approaches and in the tunnel. If this volume of traffic had to be detoured one mile while repairs were made, the financial loss to the people within a radius of fifty miles of Pittsburgh would be at least $2500 a day for operating expenses only. Such figures should be given consideration in designing and locating new highways in order to eliminate future repairs to the greatest possible extent and thereby save the cost of detouring traffic.

H. S. Mattimore:* One interesting study that is now being made in highways of special importance to automobile users is concerned with reducing the time of closing of a highway surfaced with concrete, or one that has a concrete base. The older specification which was followed in practice for a great many years called for the closing of a concrete road from 18 to 21 days. So far as our investigations determine, there was no logical reason for closing the road for this length of time. It seems to me that it was a case of following the old practice which might have been necessary in the early days when materials were not of as high a grade as at the present time.

Procedure along this line in Pennsylvania is to determine from transverse tests in the field what the carrying capacity of the road is, and to open the roads when the slab has attained a strength to carry the traffic with a sufficient factor of safety. The time of opening roads will vary with different atmospheric conditions, consistency of the concrete laid, and, to some extent, the materials used. From this stand-

*Engineer of Tests and Specifications, Pennsylvania Department of Highways, Harrisburg, Pa.

point no general definite figure for transverse strength can be followed.

Mr. Eckels stated that calcium chlorid is used in our work. I wish to inform the engineers who are not familiar with the use of this salt that it is by no means a radical move on the part of the Highway Department. We have made extensive tests on the use of this material as a curative agent, and we have in the state two short stretches of road which are now over nine years of age. These were under constant study for five years prior to calcium chlorid being allowed as a curative agent in the specifications.

I appreciate the opportunity to attend this meeting. I have heard throughout the state many favorable comments on the meetings of your Society, and I hope to be able at some future date to have the privilege of attending some of your other meetings.

Edward G. Lang:* As you know, I am a sort of paradoxical office holder, inasmuch as I have had no technical training as an engineer, and I try not to sail under false colors.

I am gratified to attend this meeting of engineers because I have so much to learn about my particular job. The more I learn the more I find there is to learn. I have attended engineering conferences throughout the length and breadth of the land, and I find that the standardization of road construction is absolutely impossible; that all the elements that enter into road construction must be predicated on the character of the traffic that the particular road must bear, the atmospheric conditions, the materials that are to be had in that particular location, and the burden that must be carried. All these must be given the closest scrutiny and study. I have met engineers from California, from Maine, from all portions of the country, and I find they rarely agree on methods to be used in road construction because they do not understand the problems of other sections of the country. I am struggling day after day to learn something more so that my humble services to the city and to the people at large may be in the very highest measure returned with an accounting of my stewardship. As I go around day after day it is always a pleasure to meet with you gentlemen and hear the words of wisdom that are coming from those who have the time and the opportunity to study these great problems of road construction. As I said the other evening at

*Director Department of Public Works, City of Pittsburgh, Pittsburgh.

your gathering in this building, it is desirable to have a technical education; but with all the technical training and the education that comes to one in the technical schools, I say, and say advisedly, that technical training and education are no substitutes for the application of good common-sense in whatever line of activity a man may be engaged.

J. L. HERBER:* Not very long ago I had occasion to look up the records pertaining to some of our state highways in this part of our Commonwealth and I was interested to find that the only highway that the state of Pennsylvania really owns is the National Pike. When the federal government in 1806 started to build that road, it did so because William Penn had set aside, and conveyed to the federal government, a grant 66 feet wide and 90 miles long—the only highway the state really owns. In every other instance, the only rights we have are easement rights.

In looking up other historical material, I found that Pittsburgh was really the center of activities in the early days in Western Pennsylvania from the highway point of view. If you will look at the records of corporations formed in our own state, you will find a natural trend such as you would see in any community. Of course the first corporations were churches and then there were toll bridges, and they were followed by toll roads, and they in turn by canals and railroads. Pittsburgh had a series of toll roads coming in from several different directions. One coming in from Brownsville—and Brownsville was on the map in those days, because she was on the National Pike and Pittsburgh was sitting off in the woods. There was another toll road running to the west, to Steubenville, Ohio, 50 feet in width—the Steubenville Pike—then the William Penn Highway, with which you are all acquainted, the Lincoln Highway and the Perry Highway, each corporation having a grant of 50 feet in width. One along the Allegheny River I think was 40 feet in width. We are just completing the cycle in carrying out what they set out to do in the eighteenth century.

We find that back in 1784 Pittsburgh was engaged in a quarrel between the Governor and the Legislature as to how much money

*Division Engineer, State Highway Department, Pittsburgh.

they should set aside to improve the Lincoln Highway. Finally they set aside $2500 to improve it between Chambersburg and Pittsburgh, and that was one of the main subjects of discussion at that session of the Legislature.

In 1791, $400 was set aside for improving what was known as the Perry Highway between Meadville and Waterford, and $400 also for that portion between Meadville and Mercer. Think of the remarkable comparison between $800 and what we are doing to-day.

The subject of right of way is a live one at present. We must know what is our legal right of way, and naturally we go back into early records. In many cases these are responsible for relieving us of a lot of trouble. Where we find it necessary to go outside of the legal right of way, either for safety or distance in relocating highways, it becomes necessary to make arrangements with the property owners affected in accordance with the Acts of Assembly. These questions must be adjusted between the county and the property owner. That is a serious problem. You can readily understand that where you are in a congested section and property is so valuable, the question as to how far we shall go in imposing damages on the county in which that project is located is one which can not be overlooked. It requires the general co-operation of the county authorities, and I can say to you honestly that there has been a very noticeable, a very remarkable, improvement in the viewpoint of our various county officials in recognizing the importance of the thing Mr. Eckels has brought out—the building of respectable highways from the standpoint of safety. That is one of the things that give us genuine pleasure in our planning for the future.

C. B. Stanton:* I wish to say merely that I came here in response to your notice and also in response to an invitation from the men in my class who are here to-night to gain information on highways. I know we will profit by what we will hear, because it is from just such men as you that we can learn things that are not in the text-books. We take every opportunity we can to come to meetings of this Society to get just that type of information. I thank you.

*Associate Professor of Civil Engineering, Carnegie Institute of Technology, Pittsburgh.

H. R. MOFFITT:* I believe there is no problem before the public to-day which carries more interest than highway improvement. No matter where I go I hear discussions pertaining to the matter. Every place where men gather, at luncheon clubs, meetings of civic organizations or on the street, whether they are engineers or business men, the subject of highway improvement in one phase or another comes up for discussion. The standard of highway development is being raised and the extent of highway improvement is increasing yearly.

Comparing highway development with railroad development, highway engineers are being confronted at this time with problems similar to railroad problems. Prior to 25 years ago, railroad transportation lines were being rapidly extended all over the United States. Construction was not made on the best alinement and grade for long trains moving at high speed. Consequently, in the last 25 years railroad development has been largely along lines involving corrections in these features. Highway development has now reached the stage where one of our greatest problems is the rectification of alinement and grade in congested areas in order to provide reasonable safety for traffic which is permitted by law to move at greater rates of speed each year.

Generally, the stage of rapid expansion in highway development has passed and many of our construction problems at the present time are in the nature of reconstruction.

J. T. CAMPBELL: Mr. Herber stressed the question of right of way. I am interested in that, but from a different angle. I do not know whether Mr. Eckels can answer this question, but I have noticed recently in traveling the main highways of Pennsylvania that where side roads intersect the main road, stop signs have been erected. In a number of states the highway departments have designated main highways as arterial highways. The motor code of Pennsylvania still has the provision that the man on the right has the right of way. I wonder whether these stop signs at cross-roads are gradually developing arterial highways out of our main highways.

SAMUEL ECKELS: I can answer that question in this way. The purpose of the through-traffic stop sign—the full intent of that legis-

*Assistant Division Engineer, Pennsylvania Department of Highways, Pittsburgh.

lation—is the creation of arterial highways. When we determine on an arterial highway we at once proceed to erect these stop signs. We do have the right, however, to erect those signs on secondary roads where there is a large amount of traffic.

J. T. Campbell: Why doesn't the Department go all the way and simply designate the arterial highways and change the motor code to take care of that?

Samuel Eckels: Most of the developments in highway construction are gradual. That was left open originally, and is still left open, for the reason that we have to deal with various people in different counties of the state. For instance, at the intersection of the McMurray Road and the William Flinn Highway, Route 108, just east of Morganza, there is a through-traffic stop sign. The wording is very clear in the law. We may erect a sign of a certain description, a certain height of letters, but the words are not arranged exactly the way the law states. A ruling of the Attorney General says that the arrangement of the words is left to the discretion of the Secretary of Highways. A man recently approached Morganza from the east on the Morganza Road, approaching the William Flinn Highway, and did not slow down or stop and was arrested. He was taken before a magistrate and fined. He appealed and carried the case to court, and the Washington County court decreed that the sign was not legal, and that the arrangement of words on the sign should have been "Through Traffic Stop," instead of Through Stop Traffic.

You see, the judges and other people are so highly technical that the Legislature is very careful, in delegating authority of that kind, not to cover the entire state at one time, but make it a gradual development. When we were given that authority under the Act of 1927, we picked out several highways to try the "through-traffic stop" or arterial highway sign. The Lincoln Highway, the Yellowstone Trail, running from Buffalo to Erie, the Susquehanna Trail, the Lackawanna Trail, and from Harrisburg to York and on to Washington. We erected these signs over night and published the fact that these were places at which the motorists were supposed to stop before

entering and it was done according to the provisions of the motor code. After a time people became accustomed to it and we would enforce the law.

This is what we are up against. On certain sections of the Lincoln Highway, between Philadelphia and Pittsburgh, we found at least 100 different interpretations of what that sign meant. To no two counties from one end of the state to the other did that sign mean the same thing. They all admitted it meant "Stop," but whether back 10 feet from the intersection or in the middle of the road, or whether the motorist should go on across and stop and see if he missed anything or anybody, no one could tell. We are unable to solve all the problems they have raised. Does it mean that once you have stopped you are within the law? If the motorist stops and then shoots across, he will only get into trouble if it is a highly traveled road. There isn't any control governing the traffic in any direction at that point. We have not been able to solve it.

J. T. Campbell: I thought the Department was simply trying to detour around that question. In Tennessee that sign means that the man at the cross-road has to wait until there is nobody in sight before he can cross.

John M. Rice:* I wonder if Mr. Eckels knows whether any traffic surveys have been made since 1924 and, if so, how the predictions based on the 1924 surveys have been borne out. I also wonder whether the Department has any statistics on the number of families that have two cars. It has come to my attention that there is a campaign being conducted by the automobile manufacturers advocating the idea that a family ought to have two cars. I wonder what the results have been as far as Pennsylvania is concerned.

Samuel Eckels: We have made further studies and checked up traffic on certain highways (not all of them), and in a great many cases we have found that the predictions have been very, very close, within a variation of not over five per cent. in any case.

Regarding the question of two cars to the family, we do not have any records. The best records of motor-car traffic are available

*Consulting Engineer, Pittsburgh.

through the National Automobile Chamber of Commerce. We have neither the time nor the inclination to go into such statistics.

JOHN M. RICE: The National Automobile Chamber of Commerce claims that 18 per cent. of the cars are now in the class of two cars or more to the family. That covers the whole of the United States. I wonder what it is in Pennsylvania. It seems to me it should have quite a bearing on future traffic estimates.

SAMUEL ECKELS: It may have a vital bearing on future traffic, but our future traffic estimates are not based on such a figure, but on one man driving one car. If he has a family and has two cars, the two cars will be out. The ratio as to the number of people, and the number of cars in use is absolutely dependent on ownership.

JOHN M. RICE: What is the number of people per automobile in Pennsylvania?

SAMUEL ECKELS: Seven to one. There is one interesting fact that has not been brought out, and that is the amount of foreign traffic on the Pennsylvania state highways. In the traffic survey of 1924 it was definitely determined that 10 per cent. of the traffic on the highways of Pennsylvania was foreign traffic—that is, traffic which originated outside the state—and that traffic brings into the state of Pennsylvania approximately $500,000 a day. It is almost unbelievable. If I am correct, it is estimated that the tourist and foreign traveler spends $182,000,000 a year in the state of Pennsylvania. In Texas the tourists spend $10,000,000 and they make a great fuss about it, yet we take no notice of it when they spend $182,000,000 in this state. If you are working it out to cover the entire state, as it is necessary for us to do, it would be a revelation to you. Some 2500 school houses have been consolidated into 500, with a better corps of teachers, better buildings, and better conditions throughout. Communities have been entirely rebuilt. Educational institutions are better, and this in all cases appears to be in the ratio of construction of new highways in the district.

I have been in possibly twenty-five states during the last year and I can say truthfully that it is admitted by the state highway

commissions of every state in which I have visited that the state highways in Pennsylvania are by far better maintained than any other state highways in the United States.

J. P. LEAF:* I take off my hat to the State Highway Department, for it has certainly done a lot in Pennsylvania. I was very much interested in what Mr. Herber says and I would like to ask him a question. I heard it said when I was a boy that in Pennsylvaia people put roads on ground they could not use for anything else. Is that a fact and are they still doing it?

J. L. HERBER: There were some mistakes made, and we are ready to admit that we have made some.

J. P. LEAF: I was interested in the remarks of the speaker on the elimination of grade crossings. How rigidly do they insist on five per cent. on main lines and a maximum of seven per cent. in the elimination of grade crossings?

SAMUEL ECKELS: We go to the Public Service Commission and demand that those conditions be met, and we usually get results.

J. P. LEAF: I have helped eliminate a dozen crossings and I have always had a row about grades. The fellow building it always wants eight to 10 per cent. and the crossings are almost impassable five or six months in the year.

SAMUEL ECKELS: We fight to the limit on that. That is only common-sense, and I may state to the students here from Carnegie Institute of Technology that if they do not have horse-sense they might as well stay out of engineering work.

In the operation of the State Highway Department we deal up to the present day with only 5,000,000 people and the other 5,000,000 leave this 5,000,000 to deal with us. We issue 1,600,000 licenses and 1,800,000 driver's licenses. I believe they affect on the average 1 to 5, so you see we are directly in touch with practically every man, woman

*City Engineer and Consulting Engineer, Rochester, Pa.

and child in the state, and there is bound to be more or less politics in it. I will say that the majority of people in Pennsylvania think they know more about road construction than any engineer that was ever born; and, further, that 998 times out of 1000 they are wrong, and in the same proportion the engineer is right.

J. P. Leaf: I have been in the road game a good while myself. There is a limit for everything. Rails, cross-ties, and road-bed will carry a certain amount of weight. Brick, concrete, and asphalt have their limits. It is always a question in my mind if the limit is not exceeded by permission to haul 13 tons over any road we now have.

We have a great many state highways 14 feet wide, and a great many 16 feet wide. The state allows a vehicle eight feet wide to go along that road. If two of them meet there will be trouble getting past. A truck can put on chains an inch thick, carrying four tons on each wheel, and go upon our streets and the effect is simply ruinous. There is nothing we have for paving streets that will withstand that impact. It does not seem right to me to assess the widows and orphans to pave a street and then let any one go over that street with a vehicle as heavy as a locomotive. The other day a fellow ran a 29-ton steam-shovel on a road. They had him arrested and the court said the state law excepted steam-shovels. You can't make laws for steam-shovels. They can go up and down the road whether you say so or not. If he paid for building and maintaining the road it would be all right, but he never has paid and never will pay to the local authorities anything like the damage he does to our streets. The suggestion has been made that the state highway authorities should make a man who runs a truck keep within the limit. That would keep him off the road or make him go on a pneumatic tire, and that would solve the problem immediately. The chain would not go through the road; it would go into the tire.

Samuel Eckels: The matter of weights, widths, etc., is involved in the acts of the Legislature and we merely carry out the laws. You have the power in your own hands, in your own borough, to regulate the traffic, if you desire.

J. P. Leaf: But not on state highways.

SAMUEL ECKELS: We do not experience the heavy chain on our highways. One reason is because we clear our highways of the snow and ice promptly. For practically every hour in the year you can travel on the state highways and they are clear of snow and ice. We find when you get into some boroughs and towns you can not get along at all, while the state highways are as dry as in summer.

We are opposed to excessive width of vehicles. We have opposed the increase in weights. Allegheny County is as much responsible for excessive weight of trucks as any other 10 counties. They wanted to raise it to 39,000 pounds, and they won out. As far as the Engineering Department of the State Highway Department is concerned, we have no other alternative than to enforce the law the Legislature imposes upon us.

R. H. HELICK:* I believe it would be interesting to know something about your road maintenance work. Do you have a fixed ratio of men per mile of road, or does the size of the gang depend on local conditions? You know how many men you have in all and can probably arrive at an average per mile for the entire state. Do you differentiate between primary and secondary roads as regards this ratio?

SAMUEL ECKELS: We have in the state of Pennsylvania 53 maintenance divisions. That is quite a detail, of which I have general knowledge, but I believe Mr. Herber could answer that better than I can.

J. L. HERBER: After it is delegated from the main office, the actual execution of the maintenance work rests with the division office. The division office is organized in this way. For each division there is a maintenance engineer who is responsible for all maintenance activities in that division. He directs the activities of the maintenance superintendents. There is one superintendent in charge of each county in the division, and each maintenance superintendent has an assistant superintendent. The actual execution of the work is carried on by means of the foreman and caretaker system. In some counties, high-

*Maintenance Engineer, Department of Public Works of Allegheny County, Pittsburgh.

ways are so located that the work can be most efficiently carried on by combining 20 or 25 miles of road in one district and allowing a foreman to take care of that with as many men as he needs to keep it in good condition. There are other sections where it would not be advisable for one foreman to attempt that mileage. He might have to travel 25 miles in a straight line to keep busy. In those cases we have caretakers, each of whom maintains anywhere from five to ten miles of road, the mileage depending on the type, and the character and condition of the soil or pavement.

R. H. Helick: I should like to get the policy of the state concerning the taking over of county bridges as recently authorized by the Legislature.

Samuel Eckels: That policy is being formulated right now. We do not take over the bridges, or are not compelled to, until June 1, 1930. At the present time there are very few state highway bridges of long span. Practically all of these county bridges are maintained by the county. We can not tell you what our policy will be or how soon we will take them over or how many we will take over this year. It is a big problem, involving some 2500 bridges. We are making a complete reorganization of our Bridge Department. We are looking for good bridge designers.

E. V. Braden:* It would be interesting to know what your policy is towards highways through smaller towns. We travel your beautiful highways until we come to a small town and then we bump along for a mile or so. The town authorities say they are not going to do anything about it, that the State Highway Department is going to pave such streets. Can you confirm this?

Samuel Eckels: If you have traveled the state in the past two years, you have found that we have performed quite a lot of construction work in boroughs. We may have missed yours. If we did, it is because your borough is not progressive enough to come along and pay the additional cost in excess of 18 feet in practically all cases. After June 1, 1929, it will be necessary for us to take over the main-

*Chief Engineer, Pittsburgh, Chartiers & Youghiogheny Railway Co., Pittsburgh.

tenance of streets up to a width of 20 feet, the boroughs to bear the cost of additional width. We are limited in the amount of money we can spend on these borough streets, but we believe we will have enough money in the next 10 years to overcome that condition and will be in such shape that we can offer aid to any borough on the state highway routes.

You may think we have so much money we can do practically anything in the State Highway Department. When I say to you that we supervise the expenditure of a million and a half a week throughout the year the figures may run away with you. That is an actual fact. But we are controlled by the Legislature as to where that money shall be applied. For instance, in the present session of the Legislature they passed the so-called Wheeler Act, which appropriated $23,500,000 to be allocated to various counties of the state on the basis of the mileage of unimproved state highway routes, with the fundamental qualification that no county shall receive an allocation of less than $200,000 or in excess of $600,000. That is a pretty big dip into the pork barrel. In addition to that, $2,000,000 is appropriated for state-aid work. State-aid highways are constructed on the basis of 50 per cent. by the state and 50 per cent. by the county and township, or in the ratio of 65 to 35 per cent. in seventh and eighth class counties. The sum of $6,000,000 is appropriated for the improvement and maintenance of township highways, to be matched by the various townships in certain proportions set up in the law. In some cases we pay as much as 25 per cent., in others 50 per cent., and in others 75 per cent. Mr. Warren, who is a native of Pittsburgh, approved that law and we may ask him to explain that law.

There are a great many appropriations made from the motor license fund. Then we have a certain amount of money for new construction. The obligation imposed by the legislature must be met. We have no recourse other than to use that money in that particular way.

We have some interesting projects in western Pennsylvania; three of them I know will interest you. The Benjamin Franklin Highway will be completed within the next two years. The Perry Highway from the West Virginia line to Erie will be completed within two years—10 miles are completed, 10 are under construction, and the rest of the work has been authorized. We expect to complete within the next two years the viaduct over Turtle Creek Valley on the Lin-

coln Highway. The county will finance half that construction. It takes the major portion of the traffic out of Turtle Creek and East Pittsburgh.

E. H. McClelland:* Modern progress in road construction is all the more remarkable when we remember that the construction of the famous Roman roads extended over five centuries, and when we consider the earlier types of roads in America. The following specification for a high-grade, 80-foot highway just 100 years ago may be of interest. It refers to the proposed "National Highway" through Ohio and Indiana, and is quoted from "The World on Wheels," by H. O. Duncan, v. 1, p. 67. (Published by the author, Paris, 1929.)

"In August, 1829, the specifications for the road were amended and new ones issued reading:

The central part of thirty feet to be cut in the following manner: all the trees of one foot in diameter and under (at one foot from the ground) to be cut level with the surface; all from one foot up to eighteen inches in diameter to be cut not exceeding nine inches from the surface of the ground; and all trees over eighteen inches in diameter to be cut not exceeding fifteen inches from the surface; and all stumps within said centre of thirty feet must be rounded and trimmed in such a manner as to present not [sic] serious obstacles to carriages. Further, that of the remaining fifty feet, all stumps must be left not exceeding one and a half feet in height."

*Technology Librarian, Carnegie Library of Pittsburgh, Pittsburgh.

INDUSTRIAL POWER*

By J. H. Lawrence† and J. A. Freiday‡

Industrial power—the generation, application and use of power for manufacturing—is a subject ages old. Tied up as it is to man's instinctive effort to produce with the minimum bodily exertion a surplus of goods beyond his own needs, its history is the history of man's progress to the present-day intensive manufacturing development. The power created by man by his own exertion or by the use of animals was, as his knowledge grew, supplanted by the harnessed forces of nature. Windmills and water-wheels became the driving forces for his machinery. Ages elapsed before he discovered a new source of power. In fact, it was only three centuries ago that Porta ran the first commercial boiler, and only two and one-half centuries ago since Somerset placed the first steam-engine in commercial operation.

The use of steam in industry gave a tremendous impetus to manufacturing and to the application of power to its innumerable processes. The power used, however, was generated in the immediate locality of its consumption because its transmission was confined to very narrow limits.

The advent of electricity opened a new era in the history of industrial power. It was no longer necessary to use the power where it was generated, and, as a result, many industrial plants purchased their power instead of making it.

The generation of power became an industry. Large central power-stations were erected to supply the enormous demand for electricity—a demand made by factories, office buildings, homes, railroads and its myriad other users, spread out over a territory in some instances miles distant from the source of supply.

Electric power is the product manufactured and sold by this new industry, and, as with all manufacturing concerns, it became the problem to reduce as far as possible the cost of making its product. The result was that the best engineering brains in the industry were concentrated upon generating power at the lowest cost and, as a result,

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†President, Thomas E. Murray, Inc., New York.
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there have been developed the great modern power-stations we know to-day. The foresighted wisdom and broad-minded policy of the officials of the power companies in spending large sums of money in experimental and research work have resulted in securing the high efficiencies and economies that have been attained in these plants.

These companies have shown the way, but have the industrial operators followed the excellent examples afforded them? We do not think so. Until comparatively recent years, industrial plants have been designed along the same lines which existed during the early days of the central station.

Many excellent examples of power-station design may be seen in recent industrial development, but, as a whole, power-plant design in industrial concerns has been behind the times. This is largely due to the attitude of the owner, who pays no attention to this phase of the establishment and leaves the matter entirely in the hands of his master mechanic, even though this individual may have his hands full keeping the plant going. The owner generally expects this man to be a designing engineer, as well as operator and mechanic.

There are many master mechanics fully capable of designing their own plants, but generally the duty of keeping a plant in operation is all that should be expected of this man. It is absolutely necessary that the manufacturing equipment be kept in good running condition in order to turn out salable products, and the man's attention should not be distracted from this duty by the innumerable details of designing a new or an extended power-plant.

Many owners will spend time and money to investigate new manufacturing equipment in order to turn out this product at lower cost, but give very little thought to the power equipment which might be improved and give a greater return than the same amount spent on bettering manufacturing equipment.

The design of a power-plant is not a simple matter. There is more to the selection of an engine than just getting a piece of equipment which will turn out power. There is more to a boiler than just a vessel to evaporate water. A thorough study should be made to determine the economical pressure at which the steam should be generated, the rating at which the boiler should be operated, the amount of process or heating steam, and the pressure or pressures required

for this service, the cost of available fuels, the cost of equipment, and many other factors which may affect the cost of the electricity or steam generated. Many owners to-day do not realize the savings possible by the utilization of bleeder turbines, which in some plants deliver power for little more than the fixed charges.

It is our business as engineers to know how to do these things; to know the factors that must be determined before proceeding with the design; to make the proper selection of equipment and arrangement of apparatus to meet these facts; to acquire the knowledge and training that come with long and well-rounded experience in dealing with these problems and the intimate contact with the advances that are constantly being made in this highly specialized field.

It is our duty as engineers to determine for the builders of industrial plants whether it is more economical to generate or to purchase their power requirements. The generation of power by an industrial plant can not always be justified economically. It is our duty to tell them whether they should purchase power instead of generating it themselves.

The writers several years ago were asked to design a power-plant for a mill which had been making its own power for 30 years and had use for considerable low-pressure steam. The insurance inspectors had reduced the operating pressure to a point where it was impossible to carry the load. Before starting the design we suggested that a study be made of their conditions, and the result was that we recommended a further reduction of steam pressure and the use of central-station service. A new plant would have increased the cost of power.

There seems to be a general misconception even among engineers as to the cost of land for power-plants. The tendency seems to be to relegate the power-plant to that part of the property which no one else wants. This is a mistake, as the cost of the land for the power-house is only an insignificant percentage of the total cost of the plant. A study of the costs of central stations showed that land did not represent over one per cent. of the entire cost of the projects.

In New York City the cost of land for the three great plants erected in the last 10 years represents an investment of less than $1.50 per kilowatt of the ultimate capacity of these stations. Outside New York, costs are in some cases less than 25 cents per kilowatt.

We have shown two typical manufacturing plant lay-outs in Fig. 1 and 2. It will be seen that the power-plant requires very little space compared with the entire area; in fact, the cost may be ignored.

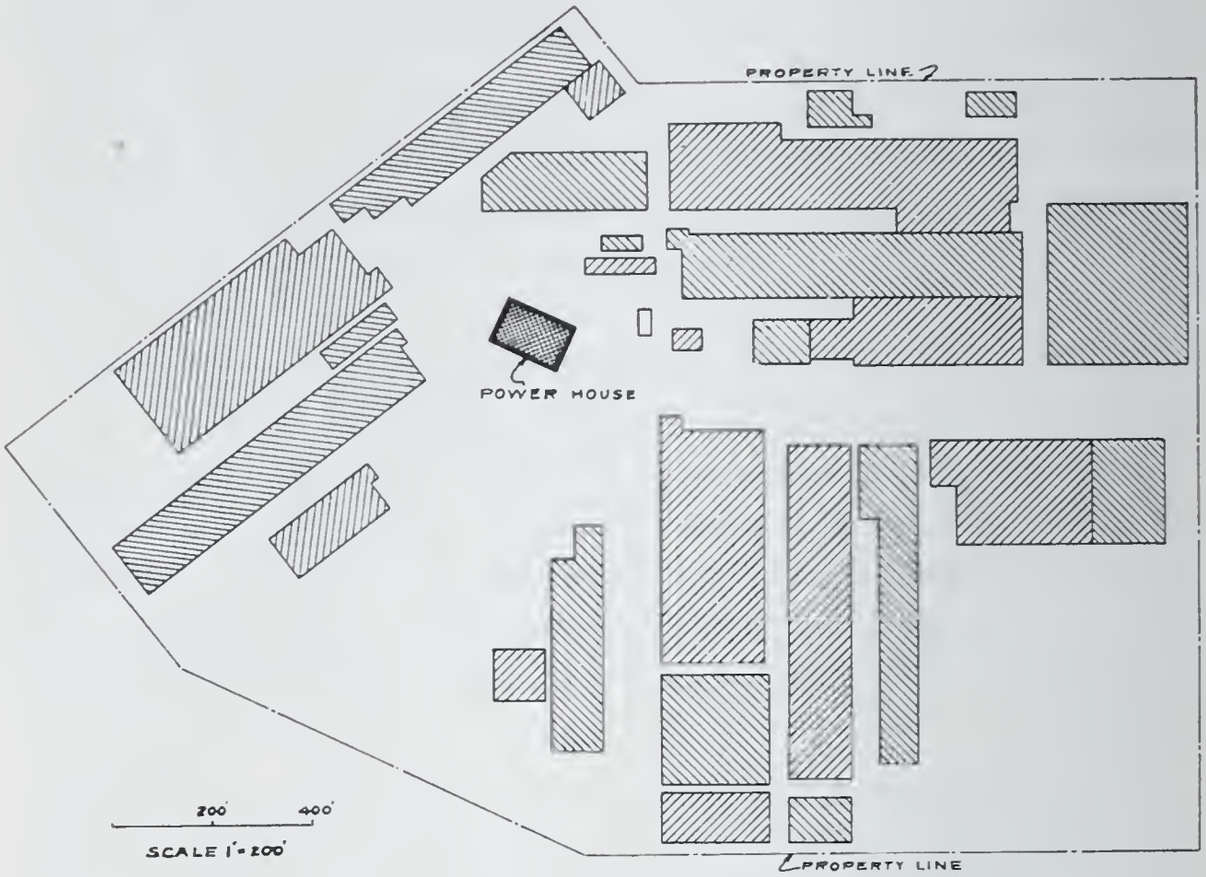

Fig. 1. Typical Plant Lay-Out.

You may criticize the lack of space for coal storage. As a matter of fact, there is very little coal stored in manufacturing plants to-day, and the same may also be said of public utilities. There are very few plants to-day with storage for more than 30 days, and many plants are not carrying one week's storage outdoors. With present conditions in the coal industry, and the railroads giving excellent service, manufacturers do not feel justified in keeping a lot of money tied up in coal.

Since the cost of land is a negligible figure, judgment should be used in the location for the power-plant. It should not be shoved off into a place that no one else wants, as very often this results in a design of power-plant that costs considerably in excess of what it should. The space allotted may be entirely unsuited to the purpose and result in expensive building construction and high operating costs.

Owners should consider the planning of the power-house with the same thought that they give to the other buildings in the manu-

facturing area. If they are progressive, they expect their business to grow, and if this does happen they want to expand their manufac-

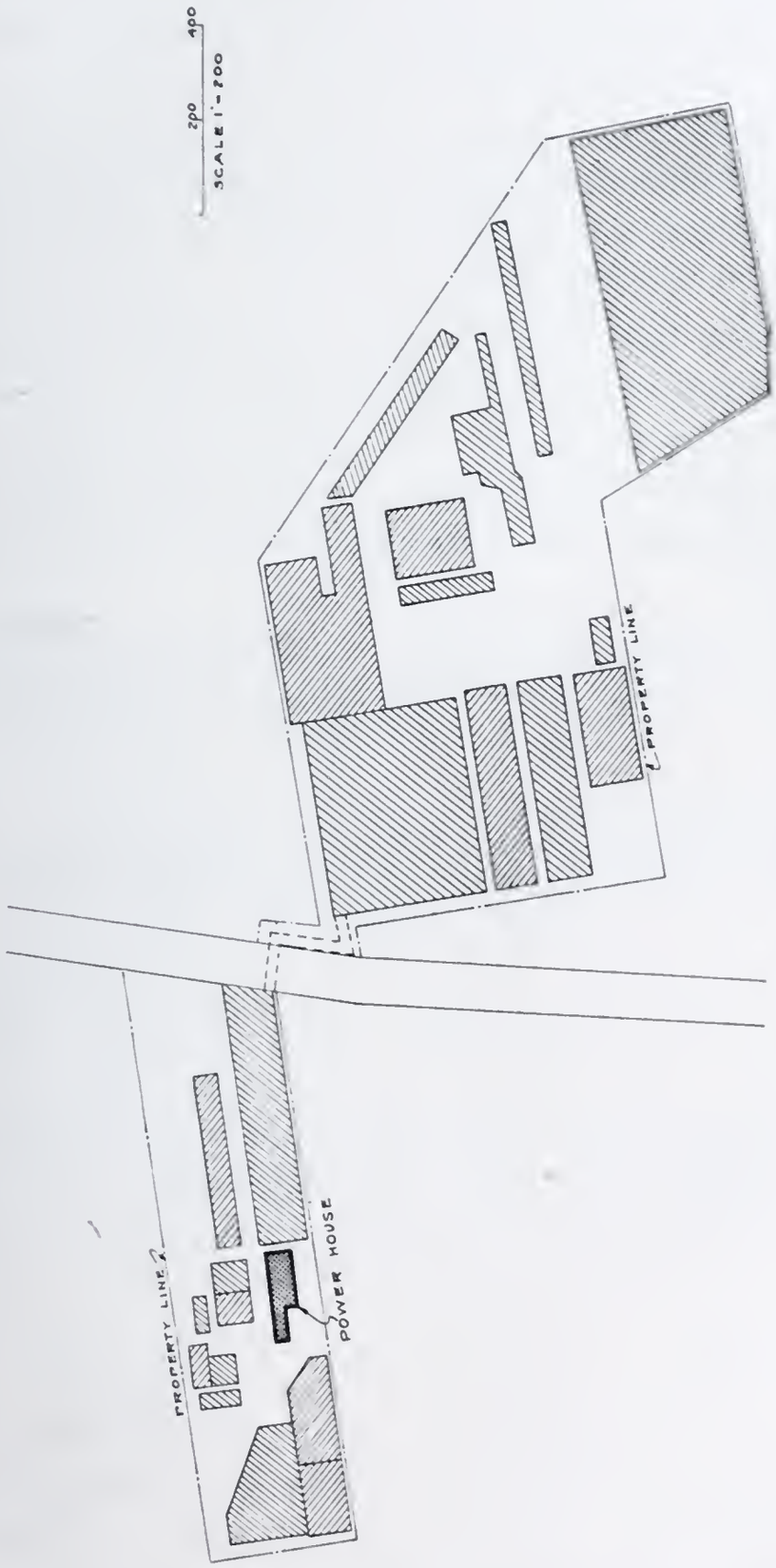

Fig. 2. Typical Plant Lay-Out.

turing facilities in a logical fashion. However, they usually do not take into their calculations the fact that their power requirements will

also increase, and thus they squeeze the power-plant into a cramped space between other buildings. As a result, when more power is required, the old equipment must be replaced with new equipment of larger capacity, or another plant must be built on another part of the plot to take the increase. The latter is generally done.

You will see this condition existing in many plants around the country. Careful planning would have provided for the extension of the power-plant, so as to obviate the necessity for an extra operating crew and for increased fixed charges.

The writers have recently looked over a plant where four separate boiler houses and three generator rooms exist, and were able to demonstrate to the owner that he could save money by scrapping all his old equipment and installing a modern plant. This condition would not have existed had he followed a logical plan of development from the start.

A little time and money spent in planning is a profitable investment. It will result in preventing many unwise developments. A dollar saved in power is worth just as much as a dollar saved in manufacturing.

There is one point we would like to bring out on power-station design which we believe is very much disregarded. We often hear the statement made that because land is cheap, the designer has been liberal with space around equipment. As stated above, land is relatively cheap, even in the larger cities. But are buildings cheap? Costs of stations show that structural costs are a very large item, in comparison with which land is a mere drop in the bucket. Let us go back again to central-station practice, for which figures are available. A study made three years ago (and the figures are fairly representative to-day) showed that the buildings cost from $25 to $55 per kilowatt of installed capacity. This cost is from 25 to 35 per cent. of the total cost of the stations.

The results of the survey are shown in Fig. 3 and are divided into two groups. Curve A is for stations in the larger cities when architectural treatment is generally given more attention than for the other group; also these stations are distributing as well as generating stations. More switching equipment with its attendant building is necessary. Labor costs are also high for this group. Curve B is for

stations in smaller communities, when most of the output goes out over high-tension lines.

It will be plainly evident from these curves that excessive liberality in space is expensive. The operating man wants plenty of elbow room, but the cost is sometimes alarming. Let us study curve B of Fig. 3. You will note that a station having a volume of 45 cubic feet per kilowatt should cost approximately $91 per kilowatt. A station having 75 cubic feet per kilowatt should cost approximately $121 per kilowatt. This shows a difference of $30 per kilowatt. At 12½ per cent. fixed charges and 45 per cent. load-factor this difference

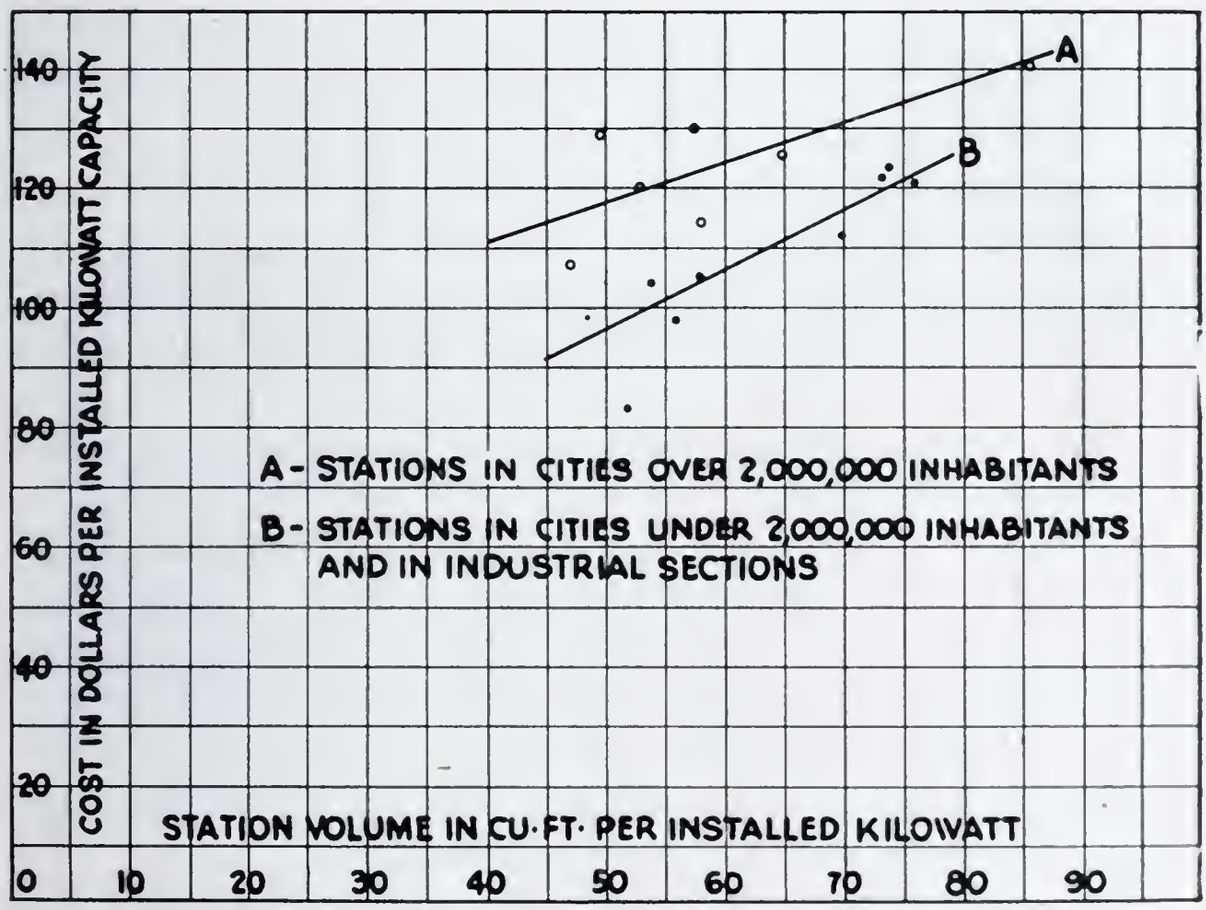

Fig. 3. Station Volume in Cubic Feet per Installed Kilowatt.

represents a cost of one mill per kilowatt-hour, or as much as the cost of labor and maintenance in the average plant studied. Liberality in space can not therefore be justified on the grounds of labor saving.

The results shown above, while for larger power-stations than found in industrial establishments, are indicative of general practice in power-plant design. The authors do not recommend using shoe-horn methods for squeezing apparatus into cramped quarters, but we should all carefully consider the value of liberality of space before we spend

our employer's or client's money. We should appreciate the fact that progress is being made in power-plant design and that we can now get considerably more capacity per square foot than we could ten years ago, and that ten years from now we shall wonder why we wasted so much space in this year of 1929. Boiler capacity has quadrupled per square foot of ground area in the last five years due to the development of the water-cooled furnace, and the same ratio holds true for the turbine rooms. The authors would not dare to predict that this experience will not be duplicated in the next five years, for they have seen such remarkable progress in recent years that it is not safe to make predictions in this field.

There is one subject we should like to mention just briefly, and that is the subject of refuse fuel. Generally a profit may be made on the burning of such fuel, but this is not always the case. The cost of labor for collecting, transporting, and preparing such fuel for firing may more than offset the cost of an equivalent amount of other fuel. Studies of certain plants have shown this to be a fact. In such plants, incinerators at the source should be used if this material must be disposed of.

Two opinions, which we believe to be erroneous are widely prevalent in industry to-day:

The first is that it does not pay to force boilers to high ratings in industrial plants, say over 250 per cent. rating. This probably is due to past experience when considerable trouble was experienced with furnace maintenance. To-day we are more familiar with this problem and it is no longer a hindrance. It is safe to say that the limit now is the economic balance between efficiency of combustion and power for fans on one side and fixed charges on the other.

The other opinion is that high ratings mean punishment of the boiler. However, this opinion is gradually being discarded, as experience has shown that boilers are capable of producing much more steam than any one dreamed of even ten years ago. If proper treatment is given to the feed-water, and the furnace is properly designed, there is no reason why boilers can not operate for months at high ratings without shut-down for repairs to pressure parts.

We have just made a study of an industrial problem which we believe will be of interest to you. This manufacturing plant has a load of 5000 kilowatts with a steam demand of 140,000 pounds an hour

at 50 pounds pressure. As the location of the plant is not definitely settled, it was necessary to make estimates for varying prices of coal from $3 to $6 a ton. Estimates were prepared for a boiler plant to furnish process steam only and estimates were also prepared for a complete power-plant with all of the steam passing through bleeder-type turbines. In order to take care of variations in the requirements for process steam, condensers were figured in connection with the turbines. In each case estimates were prepared on three different arrangements of boiler room.

For the steam and power generation three plans were considered:

Plan 1 included water-tube boilers for 425 pounds pressure, solid brick settings, underfeed stokers, and natural draft.

Plan 2 included water-tube boilers for 425 pounds pressure, air-cooled settings, forced draft, and unit pulverizers.

Plan 3 included water-tube boilers for 425 pounds pressure, water-cooled walls, forced and induced draft, air preheaters, and unit pulverizing system.

For the steam generating alone, the following plans were considered:

Plan 4 included water-tube boilers, with brick settings, natural draft, and unit pulverizers.

Plan 5 included water-tube boilers, with air-cooled settings, forced draft, and unit pulverizers.

Plan 6 included water-tube boilers, with water-cooled walls, forced and induced draft, air preheaters, and unit pulverizing system.

From the above it will be seen that we have taken into account various schemes from boilers running at low ratings and a simple lay-out to boilers running at high ratings with heat-recovery apparatus.

These plans are summarized in Table I. It will be noted that in each case provision has been made for a spare boiler, and in the case of power generation a spare turbine has been included. This is not generally done in industrial plants, but in this particular case continuity of service is essential.

TABLE I. SYNOPSIS OF VARIOUS PLANS

	Make power			Buy power		
Plan number	1	2	3	4	5	6
Volume of building (boiler house), cubic feet	350,000	340,000	321,000	384,000	345,000	325,000
Number of boilers	4	4	3	4	4	3
Horse-power of boilers	850	700	800	700	550	650
Boiler-operating pressure, pounds	425	425	425	50	50	50
Per cent. of rating with all boilers operating	166	201	235	174	222	252
Per cent. of rating with one boiler out	212	259	352	232	293	378
Total steam output, pounds per hour	158,000	158,000	158,000	162,000	162,000	163,000
Boiler-plant efficiency	73	76	83	73	76	83
Boiler-house installation cost, dollars	512,000	530,000	542,000	438,000	450,000	470,000
Volume of building (turbine room), cubic feet	125,000	125,000	125,000	None	None	None
Number of turbines	3	3	3			
Size of turbines, kilowatts	2500	2500	2500			
Output per hour, kilowatts	5000	5000	5000			
Pounds steam bled at 50 pounds an hour for process	140,000	140,000	140,000			
Total installation cost (power-plant), dollars	864,000	886,000	900,000			

The yearly costs for the various schemes are shown in Fig. 4-9.

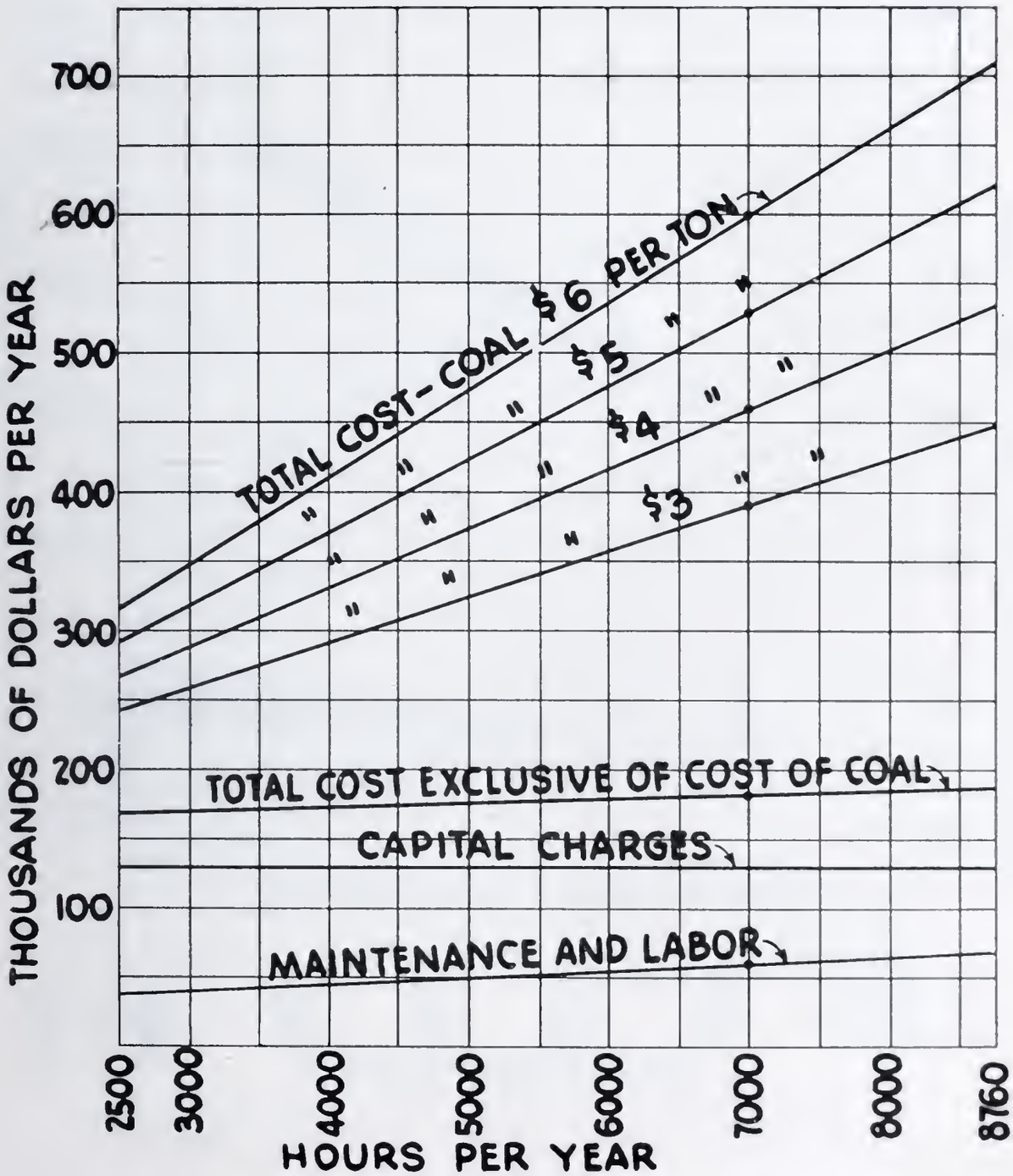

Fig. 4. Variation of Costs with Hours of Operation. Plan 1.

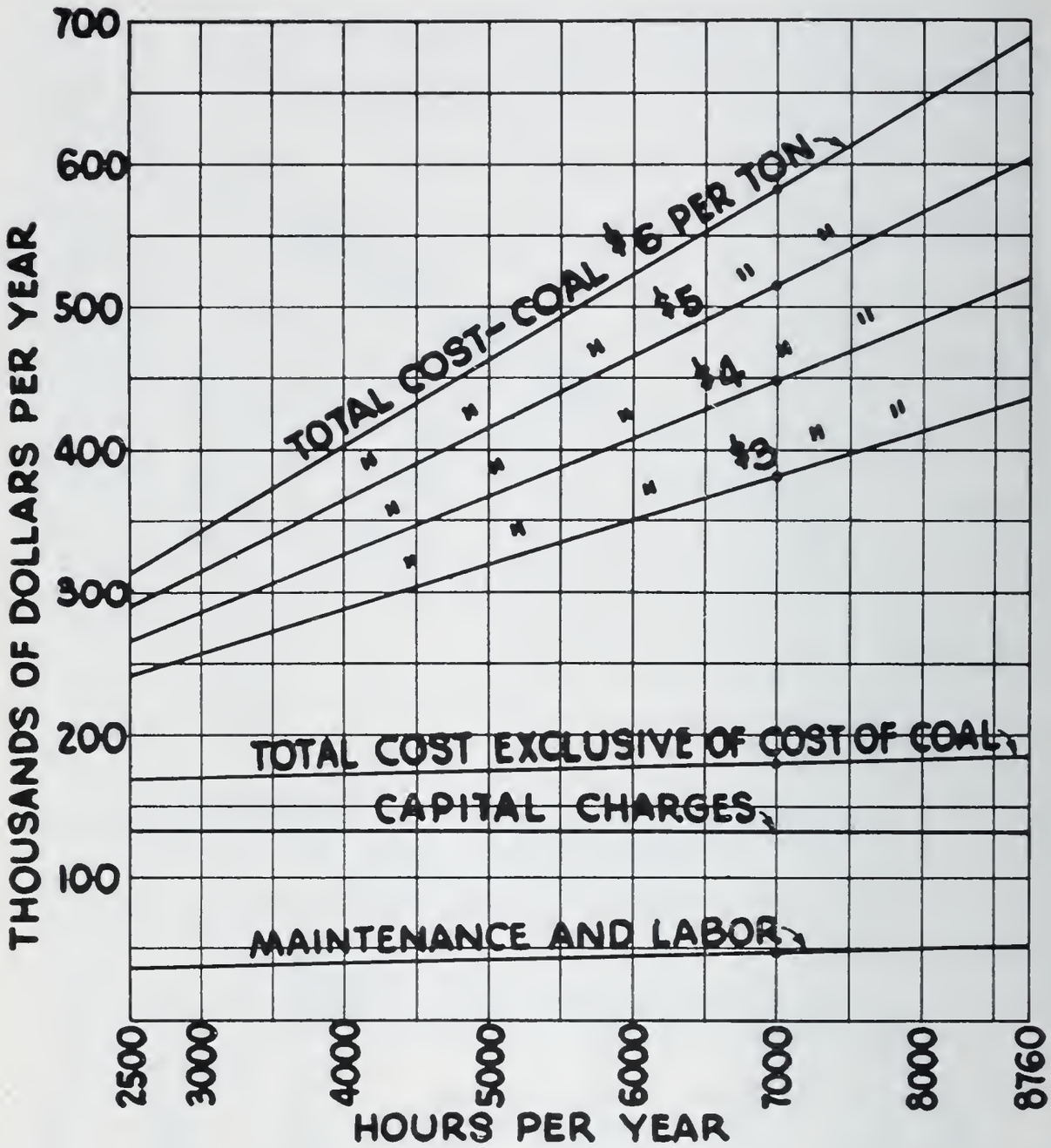

Fig. 5. Variation of Costs with Hours of Operation. Plan 2.

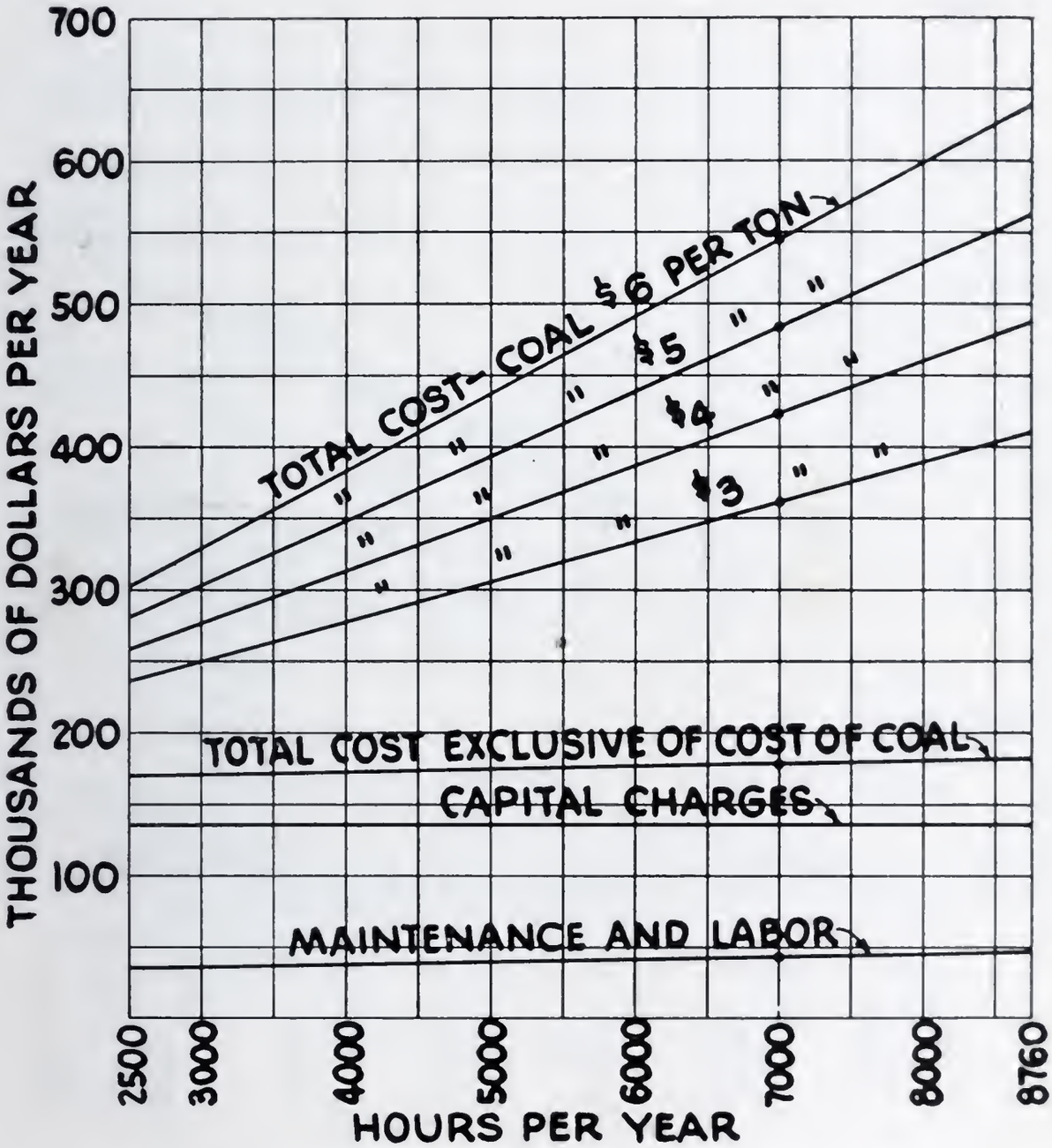

Fig. 6. Variation of Costs with Hours of Operation. Plan 3.

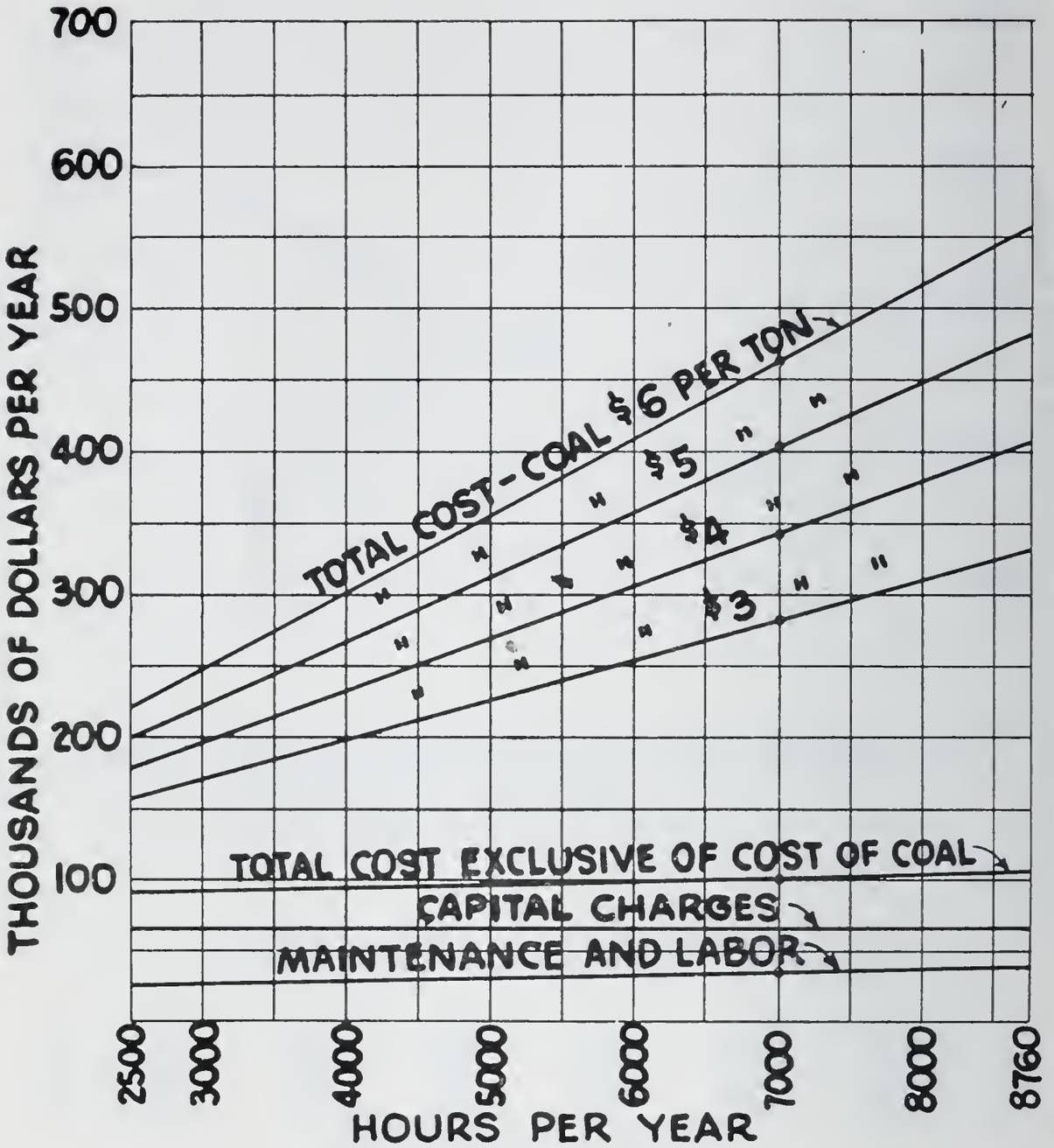

Fig. 7. Variation of Costs with Hours of Operation. Plan 4.

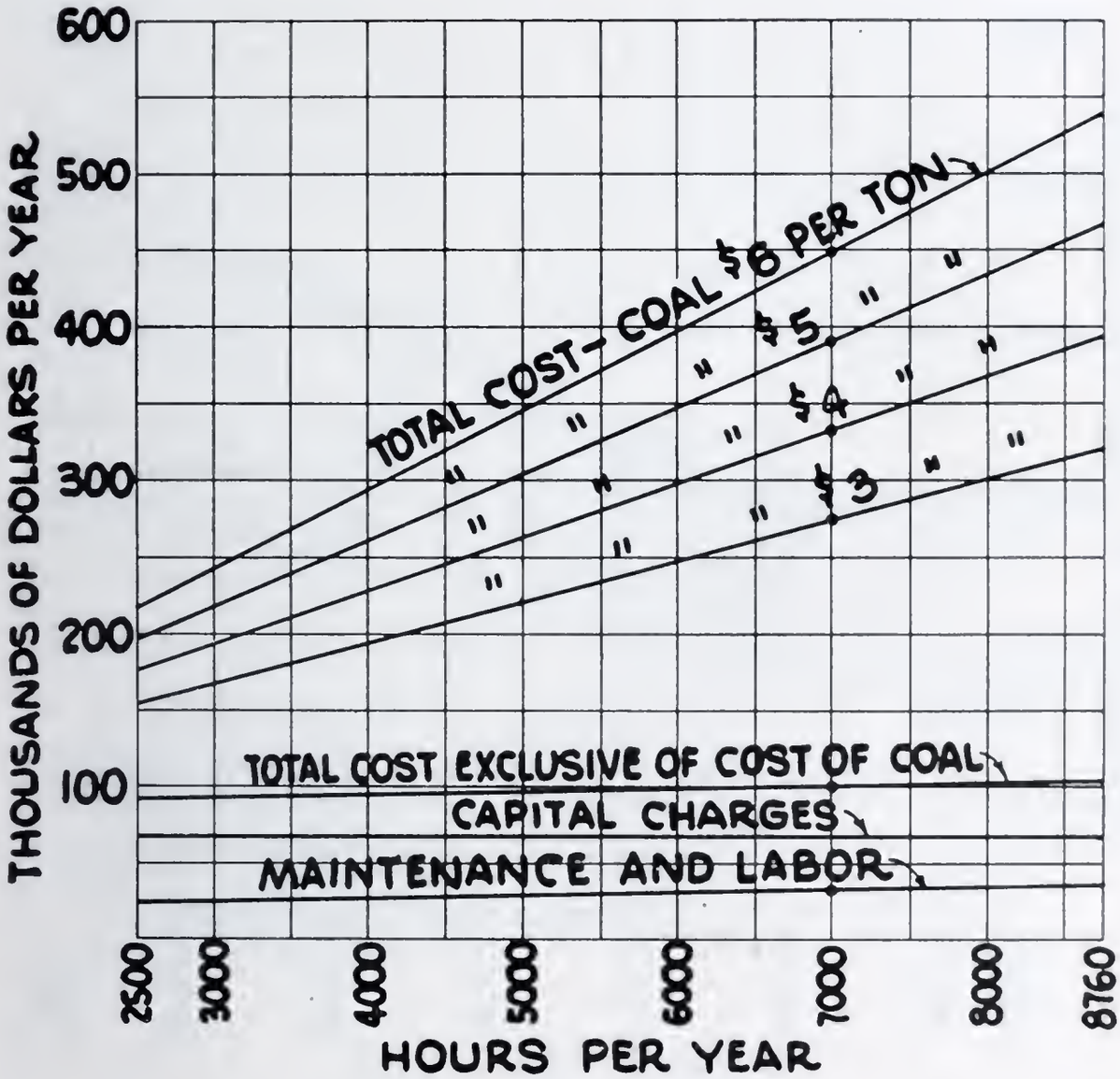

Fig. 8. Variation of Costs with Hours of Operation. Plan 5.

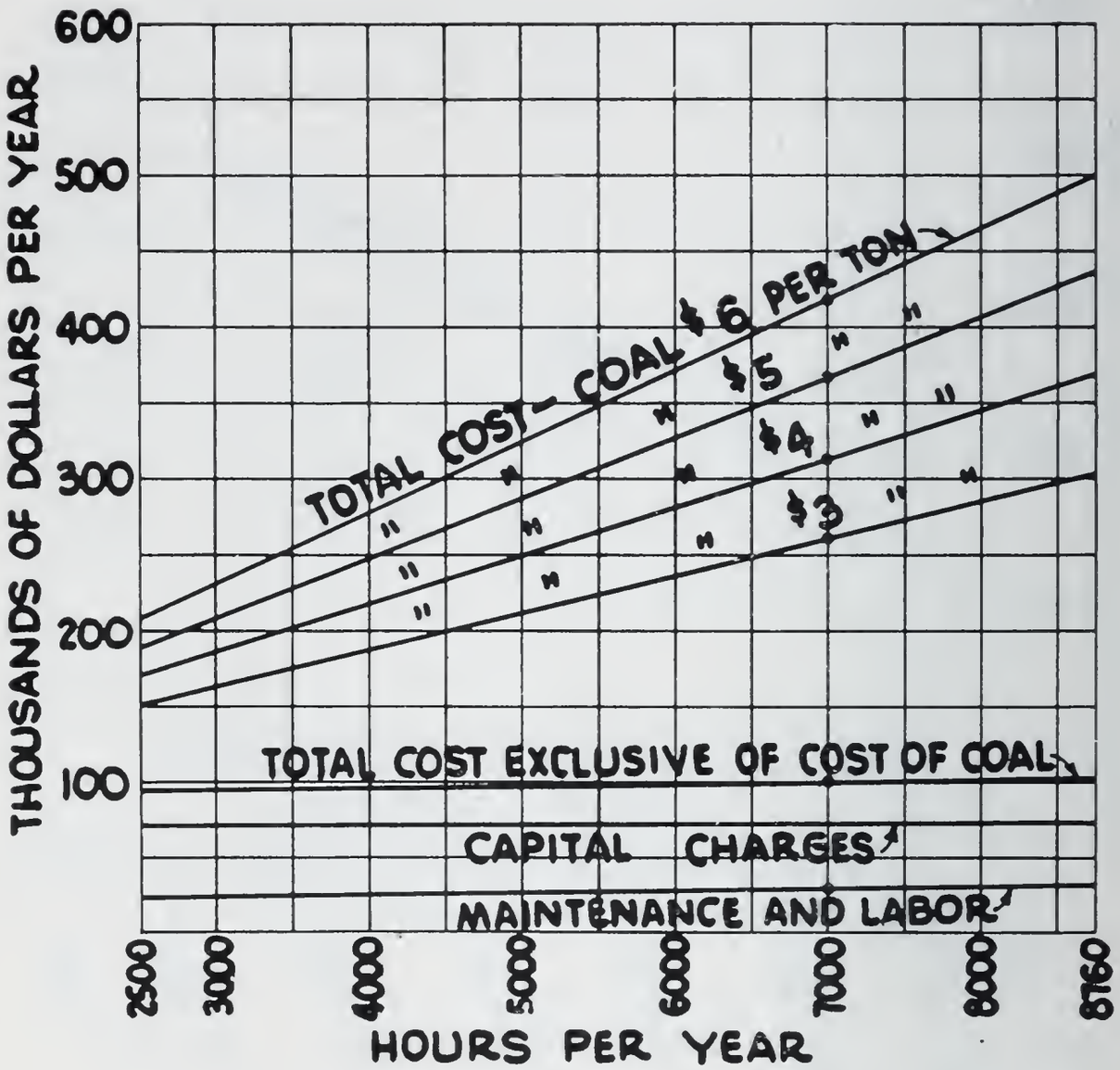

Fig. 9. Variation of Costs with Hours of Operation. Plan 6.

In preparing the yearly costs, fixed charges were calculated at 15 per cent. This is made up as follows:

1½ per cent. for insurance and taxes.
8 per cent. for interest.
5½ per cent. for sinking fund which at 6 per cent. will pay off the entire cost of the plant in 12½ years.

For convenience in comparing the yearly costs Fig. 10 is shown. This gives the costs for 4000 and 7000 operating hours a year.

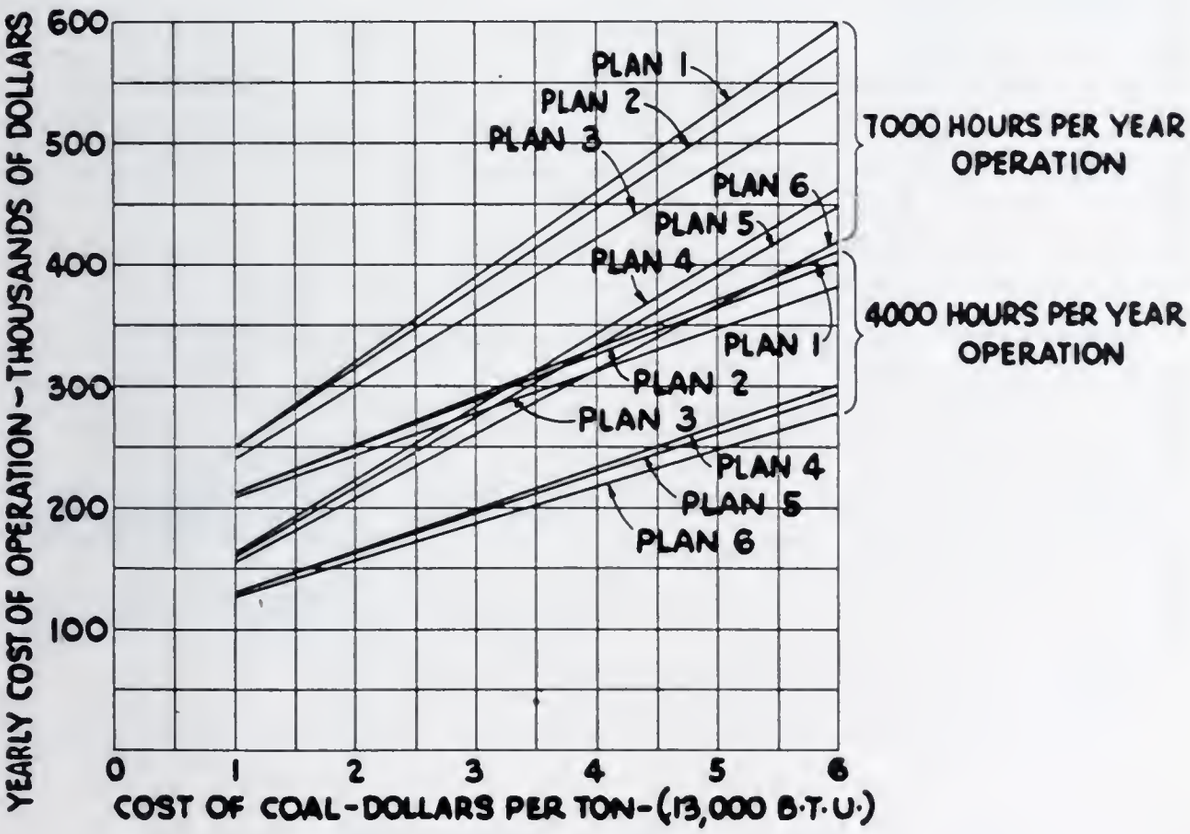

Fig. 10. Comparison of Annual Costs.

From the figures shown we have prepared Fig. 11, which shows the cost of power at various prices of coal. This is arrived at by taking

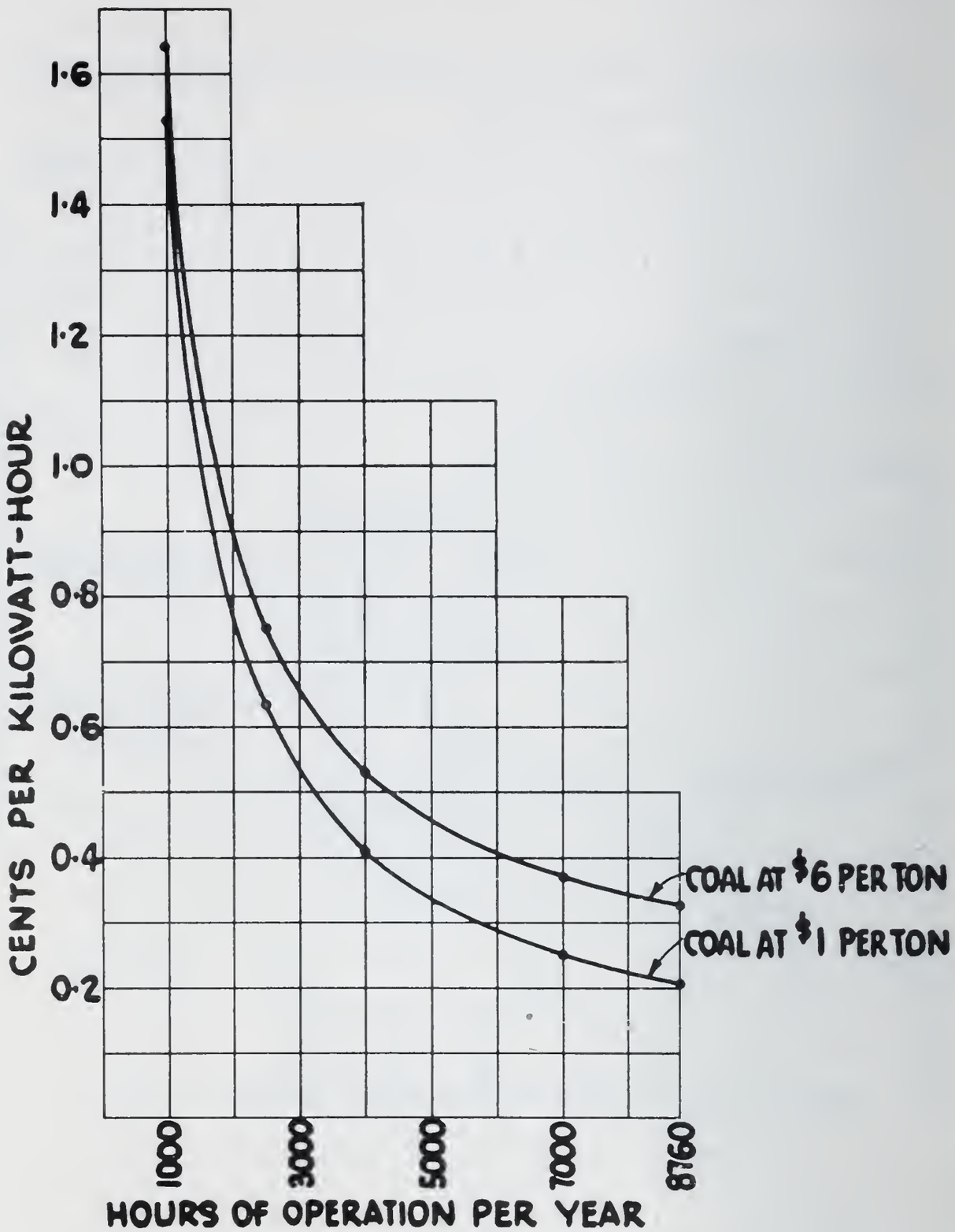

Fig. 11. Cost of Power as Influenced by Cost of Fuel.

the total yearly costs for generating power and steam and subtracting the total yearly cost of generating steam alone. The difference is divided by the number of kilowatt-hours a year. It will be seen from

Fig. 11 that at 100 per cent. load-factor the increase in price of coal from $1 to $6 a ton will increase the cost approximately 55 per cent. At 6000 hours a year the increase in cost is 40 per cent. At 4000 hours the increase is 30 per cent. and, if the plant is running only 2000 hours a year, this increase in cost of fuel will increase the cost of power 14 per cent. These results are based on comparison of plans 3 and 6.

DISCUSSION

W. B. Skinkle:* Mr. Lawrence made one remark about high rating that I thought hit the nail on the head, and that is in regard to feed-water treatment. It seems to me our modern industrial plants neglect their water treatment more than almost any other subject they have. I am sorry I was not able to study the paper before it was read so that I might be able to present an intelligent discussion. I agree with many things the speaker has said and I have enjoyed the paper very much.

W. N. Flanagan, *Chairman*:† The Executive Committee of the Mechanical Section came to the conclusion that the subject of feed-water was the limiting factor in rating in practically every one of our industrial plants, even more than furnace conditions or maintenance conditions; so we have considered it in the selection of the subject for the next conference. I am sorry Mr. Skinkle did not have the paper long enough beforehand to prepare a study because I know it would be a very able discussion.

Mr. J. A. Hunter has had considerable power-plant experience and he might be willing to contribute something to the discussion.

J. A. Hunter:‡ I have enjoyed Mr. Lawrence's paper and wish to thank him for preparing and presenting it to us. He has given us a great deal of material for thought, and has particularly emphasized important factors to which the average industrial engineer has perhaps not given as much consideration as he should; for example,

*Engineer, Pittsburgh District Power Committee, Subsidiary Companies of United States Steel Corporation, Pittsburgh.

†Special Engineer, Carnegie Steel Co., Pittsburgh.

‡Assistant Chief Engineer, American Sheet and Tin Plate Co., Pittsburgh.

the location of the power-plant with the proper allowance for future growth.

Mr. Skinkle spoke of the treatment of boiler feed-water. This is an important subject, particularly in industrial plants, as most of them have a water of such poor quality that it must be treated before it can be used for boiler-feed purposes. With this kind of feed-water it is virtually impossible to operate at extremely high ratings. If this is attempted, priming results and the water is carried over into the prime movers.

Surface condensers are not generally used in industrial plants, so that condensate is not available for boiler-feed purposes. In a few cases turbine generators and surface condensers have been installed and motors used to replace prime movers. In most cases, however, especially in the older installations, steam-engines are used as prime movers. These are either operated non-condensing where the exhaust steam is used for process work, or condensing with barometric type condensers.

I was much interested in the example given in the paper. It would be interesting to have Mr. Lawrence give his conclusions in regard to this plant.

Examining the figures given and considering 7000 hours' operation, there is an additional investment of $430,000 for generating power as compared with purchasing it, and a saving of $123,000 in operating cost, which would show a return of approximately 28½ per cent. on the additional investment, which would seem to be a rather attractive proposition.

J. H. Lawrence: Fig. 11 indicates the cost of power per kilowatt-hour. For the conditions which we have assumed, the curves show the maximum that you can afford to pay for purchased power in this hypothetical plant. If your plant runs 4000 hours a year and coal is worth $6 a ton, you could not afford to pay more than 5-1/3 mills per kilowatt-hour. If your plant runs only 2000 hours a year, you could afford to pay up to nine mills to a public utility company.

The curves on Fig. 11 are drawn in for only two prices of coal—$1 and $6 a ton. However, it is very easy to figure the intermediate points.

In our calculations we used fixed charges of 15 per cent. This represents the actual cost of the investment. The fixed charges of 15 per cent. are made up of 1½ per cent. for insurance and taxes; eight per cent. for interest; 5½ per cent. for sinking fund, which at six per cent. will pay off the entire cost of the plant in 12½ years.

We could have figured it out on the basis of gross return on the investment, but this is a very unscientific way of expressing the return on an investment.

The general impression seems to be that if you have a gross return of 15 per cent. on the investment, the money is returned in 6-2/3 years. However, as will be seen from reading the figures above, it will take 12½ years to get the investment back as during the use of the equipment, taxes must be paid, as well as insurance, and it is also necessary to pay interest charges.

Before knowing what your actual costs of running a plant will be, it is necessary to make an assumption as to the expected useful life of the plant, in order that you may determine the amount of sinking fund necessary to replace the investment at the end of the expected period.

A. D. Blake:* I would like to ask Mr. Lawrence one question about taxes. I can understand that when an entirely new power-plant is being built, the local taxes should be taken into consideration. But if the plant is merely being modernized and new equipment has been put into the building, do the local tax assessors take that into account? Don't they as a rule simply assess the value of the industrial plant as per the former methods of assessment?

W. B. Skinkle: I think there are about as many rules for tax assessment as there are tax assessors.

J. H. Lawrence: That is not always the case. I have known of industrial plants like that putting in new boilers, and the tax assessors saw the improvement and increased the valuation of the plant. Sometimes you can get away with it and sometimes you can not. It all depends upon how strong you are politically.

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J. A. HUNTER: Until quite recently there has been a feeling that central station power was not altogether reliable due either to trouble in transmission lines or in the central station itself. However, this situation has been improved due to the installation of better transmission lines and to the interconnections between the various central station plants, so that now the industrial plant is almost assured of 100 per cent. power 100 per cent. of the time.

The central station plants have studied industrial power costs and have modified their rate structure to make the power rate more attractive. These changes on the part of the central station have, I believe, changed the attitude of the industrial plant towards the purchase of power from the central station.

W. N. FLANAGAN, *Chairman*: One thing interested me very much in Mr. Lawrence's paper and that is the question of the value of space in a power-plant. Of course it applies to the boiler house as well and to the generating end and likewise to the other problems of the shops and mills. Just how much is the extra space around the different units worth? It is one of the hardest things to determine beforehand, in my experience, and I suppose it is so with other people. Space is very advantageous, as any operator will tell you. The initial cost of the space can be very accurately calculated. The real problem is to predict in advance the saving by increase of working room.

Take as an example a certain boiler house supposed to deliver an average fluctuating load of about 10,000 horse-power. Six units, 27 feet wide, with about eight feet of space between boilers, and a space of about five feet behind the boilers. The restricted space is a handicap to the operators both in firing and in repairs. The question is then how to evaluate any additional space that might be provided. Suppose the distance between boilers is made 13 feet instead of eight feet. Figured roughly, the extra cost of the building is about $25,000. Also, if the depth in the rear of the boilers is increased four feet, it would cost another $19,000, making $44,000 additional investment in the boiler house. When developing 10,000 horse-power at around 68 per cent. efficiency with coal at $3.50 this boiler house would burn about $422,000 worth of coal a year. The additional building cost, therefore, of $44,000, at 13 per cent. fixed charges, would be $5720

a year. With only $500 for extra maintenance on the additional part of the building there would be a total of $6300 a year extra that would have to be earned to pay for the larger building. That means that we would have to increase the efficiency only 1½ per cent., or from 68 to 69½ per cent., to pay for it. That increase of 1½ per cent. in efficiency appears very easy to obtain, but it is very hard to prove in advance. How will we prove that we are going to get that extra 1½ per cent. efficiency in return for the expenditure proposed for increasing the dimensions of the building? While we are able to calculate almost all the other items in a power-house accurately in advance, that is one item on which there is very little concrete evidence. What we need is concrete examples and tests ranging from a marine type power-plant where space is at a premium, for instance, to a central station where there is liberal space around each of the units.

TREND IN DESIGN AND OPERATION OF INDUSTRIAL PLANTS WITH SPECIAL REFERENCE TO FURNACE VOLUME*

By Henry Kreisinger†

Introduction. The trend in industrial plants is towards larger steam-generating units. Units having capacity of 75,000 to 150,000 pounds of steam per hour are quite common. A few plants have units generating up to 300,000 pounds of steam, and one plant has units generating 600,000 pounds of steam per hour.

The pressures used in the new industrial plants keep up with the standards of large central stations. Many of the plants use pressures of 400 pounds, a few use 800 to 1400 pounds, and one plant uses 1800 pounds. High pressures have special advantages in the industrial plant. The high-pressure steam generates electrical power in high-pressure turbines, and the partly expanded steam is used in process work; thus the industrial plants can obtain the electrical power at a very low expenditure of heat, because with them the condenser losses, which are the highest of the losses in central stations, do not exist.

Fuels Burned. Coal is by far the most common fuel burned in industrial plants. It is burned either on stokers or in pulverized form. Except with very small units, hand firing is rapidly passing out of date.

The amount of fuel-oil burned in industrial plants is small. It is used where it can be obtained at prices comparable with coal. In such cases the furnace is usually so designed that either fuel-oil or powdered coal can be burned.

Blast-furnace gas is used quite extensively in steel plants. It is a by-product of the steel-making process; since its heat value is low, it is not suited for many steel-heating purposes, and it does not pay to carry it long distances in pipes. For these reasons it is burned largely under steam-boilers, where it is usually supplemented by powdered coal or fuel-oil. Blast-furnace gas, powdered coal, and fuel-oil can be burned in the same design of furnace. They are burned separately or two together.

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Natural gas is burned under steam-boilers in localities where it can be obtained at a price competitive with other fuels. It is a clean fuel, high in heat value, and it is therefore feasible to pipe it a long distance—in some cases several hundreds of miles. It can be supplemented by either fuel-oil or powdered coal. Many of the new installations are so designed that any of the three fuels can be burned with but slight changes in the burning equipment.

Efficient Units and Skilled Operators. In the recent designs of industrial plants there is a strong tendency to make the boiler rooms more spacious than was the custom years ago. With the advent of larger units, battery settings are fast becoming obsolete. The units are set by themselves, with ample space around them for easy access for maintenance and operation. Considerable thought is also given to good ventilation, daylight, and facilities for keeping the plant clean. Boiler rooms are no longer considered as places that are necessarily dirty, dark, and stuffy.

In the old days the only instruments the boiler operator had to guide him were a pressure-gage and water column. In the modern industrial plant, separate instrument panels containing all the instruments that are used in a good central station are quite common. These instruments include draft-gages, steam and gas flow meters, temperature-recording instruments, feed-water measuring instruments, and push-buttons for controlling induced-draft and forced-draft fans. Boiler dampers have suitable extension so that the draft can be controlled with a nicety from the operating floor. The instruments are found a good investment because they promote efficient burning of fuel and long continuous service of the steam-generating units.

There is a decided tendency for the steam-generating units to include economizer and air heater. Fuel is considered one of the raw materials that must be used efficiently in producing the ultimate product. The boiler efficiency in the old industrial plants was generally about 60 per cent. In the modern plants 80 per cent. is not uncommon.

The operating personnel of the modern industrial plants is of higher intelligence and skill. The fireman is no longer looked upon as the man who is no good for a better job. Intelligent and skilled

men can be kept satisfied in clean, well-lighted, and ventilated boiler rooms. The more efficient units with economizers and air heaters, and the instruments which are provided for operation, give the operators ample opportunity to make their skill and intelligence profitable to the owner of the plant.

Feed-Water. One of the most important problems in the operation of a boiler plant is good feed-water supply; but even with the best water, the make-up should be purified either by evaporators, or properly treated to avoid scale formation and the grief that goes with scale, corrosion, and other boiler ailments resulting from bad feed-water. The feed-water treatment is becoming an exact science and most of the progressive industrial plants give considerable attention to it and in many cases retain the services of a specialist in this line.

Space in Boiler Plant. The outside space requirement around a steam-generating unit varies with the size of the unit, the type and general arrangement of the equipment, and the kind of fuel and firing. Space must be provided for the insertion of the boiler and economizer tubes, superheater elements, and soot blowers. There may be other parts of the steam-generating unit that may need renewal from time to time. If the unit is stoker fired, space must be provided for the withdrawal of the stoker as in the case of a traveling grate, when repairs must be made on the working parts of the stoker. The fans and motors must also have sufficient space for proper attention, because on their serviceability depends the output of the steam-generating unit. These are the things that must be taken into consideration when the lay-out for the plant is made. At times when an old plant is modernized, space in the old building can be gained by installing new units of large capacity, but generally the old plant buildings are too low for proper housing of larger units and expensive extensions must be made. Frequently it is found more economical to make a new start with an entirely new boiler plant.

Size of Furnaces. The space that should be provided for the furnace depends principally on the steam output of the unit, the kind of fuel, and the method of firing. Tables I and II give the fundamental data from which the size of the furnace can be computed.

TABLE I. COMBUSTION SPACE REQUIREMENTS FOR VARIOUS TYPES OF FUELS IN GASEOUS, LIQUID, OR POWDERED FORM

Kind of fuel	Rate of heat liberation B.t.u. per cubic foot of total combustion space per hour: Normal range of best operation	Extreme range of operation
Blast-furnace gas	7,000 to 15,000	5,000 to 25,000
Natural gas	10,000 to 30,000	7,000 to 40,000
Fuel-oil		
Refractory furnace	10,000 to 30,000	8,000 to 50,000
Water-cooled furnace	10,000 to 40,000	8,000 to 80,000
Powdered coal		
Refractory furnace		
Low-fusion ash	6,000 to 14,000	4,000 to 18,000
High-fusion ash	6,000 to 20,000	4,000 to 25,000
Water-cooled furnace	8,000 to 26,000	4,000 to 40,000

In Table I the first column gives the range of rate of heat liberation for various fuels for the best operating condition. When designing the plant, the normal load to be carried on the unit should be fitted into this range of the rate of heat liberation. The range is wide enough for any ordinary variation in the load on the unit.

The second column of Table I gives the extreme range of the rate of heat liberation in which satisfactory operation can be obtained. This range is wide enough to take in the extreme peaks and the lowest ratings at which the unit may be called upon to operate.

The lower limit of heat liberation is generally set by too low velocity of air and fuel through the burner to produce sufficient mixing for good combustion. The air and fuel tend to flow through the furnace in parallel streams, combustion taking place only where the two streams come together, resulting in slowly moving, generally smoky flame.

The upper limit is set by various factors coming into play with the different fuels. One of the principal factors is that the process of combustion is not nearly completed in the furnace, but is extended among the boiler tubes and superheater as evidenced by the presence of flame. This factor, besides having undesirable effect on the superheat, causes high incomplete-combustion losses. It is the limiting

factor for blast-furnace gas and natural gas, and for fuel-oil when burned in water-cooled furnaces.

With blast-furnace gas the upper limit for the rate of heat liberation is low because the heat value of the gas is low, and also because the concentration of the active constituent in the combustible mixture is low.

The heat value of the blast-furnace gas is about 100 B.t.u. per cubic foot. The weight and the volume of the combustible mixture for a given quantity of heat are about twice as great as with other fuels, with the result that the gases must flow through the furnace more rapidly and do not have as much time for combustion within the furnace space. In addition to this, only about one-third of the blast-furnace gas is combustible, the remainder being inert gases, which are in the way of the active combustible constituents and hinder the process of combustion. For these reasons the furnace must be made large, giving a low average rate of heat liberation.

With natural gas, the upper limit is higher than with blast-furnace gas because natural gas has much higher heat value, and the concentration of the active constituents in a combustible mixture is higher. Nitrogen of the air used for combustion is the only inert gas in the initial mixture to hinder combustion. The heat value of natural gas is about 1000 B.t.u. per cubic foot, and the heat generated by a given weight and volume of combustible mixture is about twice that generated by the combustion of blast-furnace gas. The higher concentration of the combustible and oxygen in the mixture produces quicker combustion.

The upper limit to the rate of combustion when fuel-oil is burned in a refractory furnace is the slagging and wasting away of the furnace lining. Although the ash content of fuel-oil is low, there is sufficient quantity of it in most fuel-oils to erode the furnace lining rapidly when the rate of combustion is high and the flame impinges against the furnace walls.

With a water-cooled furnace the upper limits to the rate of combustion are flame among the boiler tubes and losses from incomplete combustion. It is true that in marine and locomotive boilers the rate of heat liberation is at times much higher than that given in Table I, but in such cases capacity is of greater importance than

efficiency of combustion. In all such cases the furnaces are small because large ones could not be placed in the available space.

With pulverized coal burned in a refractory furnace, the upper limit to the rate of heat liberation is the slagging of the ash and the consequent rapid wasting of the furnace lining. In water-cooled furnaces the limits are the slag accumulation on the boiler tubes, and the losses due to incomplete combustion. The latter can be kept low by intensive mixing, which in a water-cooled furnace can be carried on to a high degree, but the accumulation of the slag on the boiler tubes is a serious obstacle.

The limit to the low rates of combustion is low velocity of air through the burner, resulting in insufficient mixing of the air and coal. As the rate of combustion is reduced, the supply of air must be reduced in proportion, which in turn reduces the velocity of the air and the mixing. Adjustable burners which make it possible to reduce the cross-section of the air passages overcome this difficulty to some extent. If the furnace has a number of burners, some of the burners may be shut off when the rating is greatly reduced and thus sufficient velocities with good mixing can be maintained on the remaining burners.

TABLE II. COMBUSTION SPACE REQUIREMENTS FOR STOKERS

Type of stoker	Rate of combustion Pounds of coal per sq. ft. of grate surface per hour: Normal range of best operation	Rate of combustion Pounds of coal per sq. ft. of grate surface per hour: Extreme range of operation	Combustion space in cu. ft. per sq. ft. of grate surface	Approximate rate of heat liberation in combustion space (B.t.u. per cu. ft. of combustion space)
Traveling grate				
Natural draft	15 to 25	10 to 35	6 to 10	12,000 to 20,000
Forced draft	25 to 40	15 to 65	8 to 15	12,000 to 25,000
Underfeed stoker				
Single-retort type	25 to 40	15 to 50	8 to 15	12,000 to 25,000
Multiple-retort type	25 to 45	20 to 75	10 to 25	12,000 to 25,000

Table II gives the fundamental data from which the grate area and the combustion space can be obtained for a given capacity of a steam-generating unit and a type of stoker. The first column gives the range of the rate of combustion on the stoker for best operating

results. The normal load carried on the unit should be fitted into this range. The second column gives the range of rate of combustion in which satisfactory operating results can be obtained. Into this range should be fitted the peaks and the lowest rating that is to be carried by the unit. The third column gives the combustion space per square foot of grate area that should be provided for smokeless operation and low incomplete-combustion losses. The higher figures given in the table are preferable whenever the type of boiler permits, especially if high-volatile coal is to be burned. The fourth column gives the approximate rate of heat liberation in the combustion space between the top of the fuel bed and the boiler. The values given in the table are based on the estimate that 60 to 65 per cent. of the heat in the fuel fired is liberated in the fuel bed, and 35 to 40 per cent. in the combustion space above the fuel bed. It will be noted that the rate of heat liberation is about the same as for the gaseous and pulverized fuels.

The upper limits to the rate of combustion on a natural-draft, chain-grate stoker are usually lack of draft, and poor air distribution over the grate area. The lower limits are short fires and poor air distribution.

The upper limit on all forced-draft stokers is the blowing out of holes in the fuel bed, resulting in poor air distribution and unduly high cinder losses. This is especially true if the fuel is free burning and contains a high percentage of fines.

The lower limit to rates of combustion on forced-draft stokers is the difficulty of maintaining uniform fuel bed and good distribution of air. It is also difficult to provide coal-feeding mechanism for wider ranges of combustion.

Combustion space in stoker-fired furnaces is required to burn the combustible gases rising from the fuel bed. The fuel bed acts largely as a gas-producer; it distils the volatile matter and partly burns the fixed carbon. The gases rising from the fuel bed contain as much as 30 per cent. combustible which must be burned in the combustion space. The combustion process in the combustion space of a stoker furnace is similar to that of burning blast-furnace gas and natural gas; also to a large extent similar to burning fuel-oil and pulverized coal. Ordinarily, 35 to 40 per cent. of the heat in the coal fired is liberated in the combustion space.

Process of Combustion in the Combustion Space of a Furnace. At the ordinary furnace temperature the rate of combustion in the combustion space depends entirely on the rate at which free oxygen comes in contact with the combustible in whatever form the latter may exist. If the combustible is in a gaseous state, the rate of combustion is equal to the rate at which molecules of oxygen come in contact with the molecules of the combustible. The rate at which such contacts are made is proportional to the product of the concentration of the combustible multiplied by the concentration of the oxygen in a uniform mixture. If C is the concentration of the combustible and O the concentration of oxygen, then:

(1) Rate of contacts $= K\ (C \times O)$.

If the combustible burns as fast as it comes in contact with oxygen, each time a contact is made part of the combustible and oxygen in the mixture is used up and the concentration of the two is reduced. With the reduced concentration, the rate of contact making is also reduced according to equation (1). This process continues, or should continue, until only a very small quantity of the combustible is left uncombined, and the combustion is nearly completed.

If we take the blast-furnace gas containing 33 per cent. of combustible in the form of CO and H_2 and mix it with air 20 per cent. in excess of that necessary for complete combustion, the concentration of combustible and oxygen, expressed in percentage of the initial mixtures, is as follows:

C_1 = combustible = 16.6 per cent.
O_1 = oxygen = oxygen required plus 20 per cent. excess =
$$\frac{C_1}{2} + 0.2\,\frac{C_1}{2} = \frac{3}{5}\,C_1.$$

The initial rate of contacts $= K\,\frac{3}{5}\,C_1^2$.

The rate of contact making during any small period of the process of combustion is:

$$(2)\quad C\left(\tfrac{1}{2}C + \frac{C_1}{10}\right) = C\,(\tfrac{1}{2}C + a) = K\,\frac{dc}{dt}\text{, where}$$

$$a = \frac{C_1}{10} = \text{excess oxygen.}$$

On integration, equation (2) becomes:

$$(3) \quad \frac{1}{a} \log_e \left(\frac{\frac{1}{2}C + a}{C} \right) - \frac{1}{a} \log_e \left(\frac{\frac{1}{2}C_1 + a}{C_1} \right) = tK.$$

With no excess air, equation (3) becomes $\frac{1}{C} - \frac{1}{C_1} = tK.$

From equation (3) the concentration of combustible at any time during the process of combustion can be computed. Fig. 1 gives three

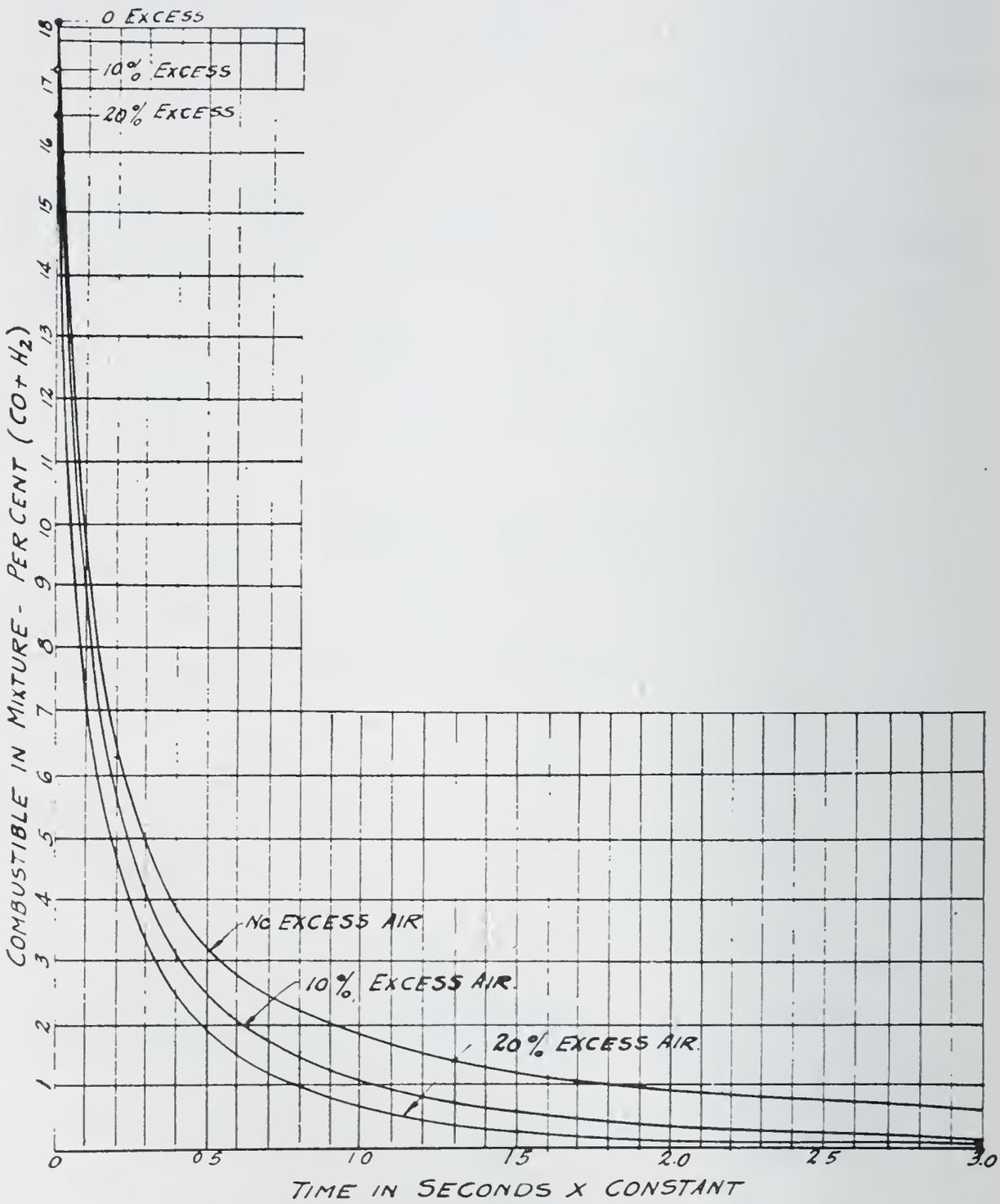

Fig. 1. Probable Process of Combustion of Blast-Furnace Gas.

curves of this equation—one for 20 per cent. excess air, one for 10 per cent. excess air, and one for no excess air. In this figure the ordinates give the percentage of unburned combustible and the abscissæ are proportional to the time. The ordinates under the curves give the percentage of unburned combustible at any time during the process of combustion, or, according to the original proposition, the percentage of combustible still left to make contact with oxygen.

The curves show that the rate of contact making or the rate of combustion is very high during the first part of the process of combustion, and rapidly decreases as the concentration of the active constituent in the mixture is reduced. With no excess air the rate of combustion decreases faster than when excess air is used. Comparison of the curves with results actually obtained in burning blast-furnace gas indicates that the constant of the abscissa is nearly 1. If the constant is unity, then in the case of 20 per cent. excess air the percentage of combustible is reduced from 16.6 to 6.8 per cent. during the first 0.1 second, or 9.8 per cent. of the combustible made contact and burned; whereas, at the end of the first second, the percentage of combustible was reduced only about 0.015 per cent. per tenth of a second. The curves also explain why in a gas-engine cylinder the combustion is fairly complete, even though the time available for combustion is short.

Very little is gained in completeness of combustion by increasing the time beyond two seconds, which shows that there is a practical limit in the size of the furnace beyond which it does not pay to go.

The curves in Fig. 1 hold true for homogeneous mixtures—that is, for mixtures in which the percentage of combustible and oxygen is uniform through any section at right angles to the gas stream flowing through the furnace. If this percentage is not uniform each part of the section will follow its own curve according to the concentration of the active constituents.

There is very little experimental information available to check up the preceding theoretical discussion, although with proper apparatus such data would not be difficult to obtain. Both blast-furnace gas and natural gas would lend themselves admirably to such investigations.

Fig. 2, which is reproduced from Bulletin 135 of the United States Bureau of Mines, gives some experimental results obtained in a coal-burning furnace fired with a Murphy stoker, and using Pitts-

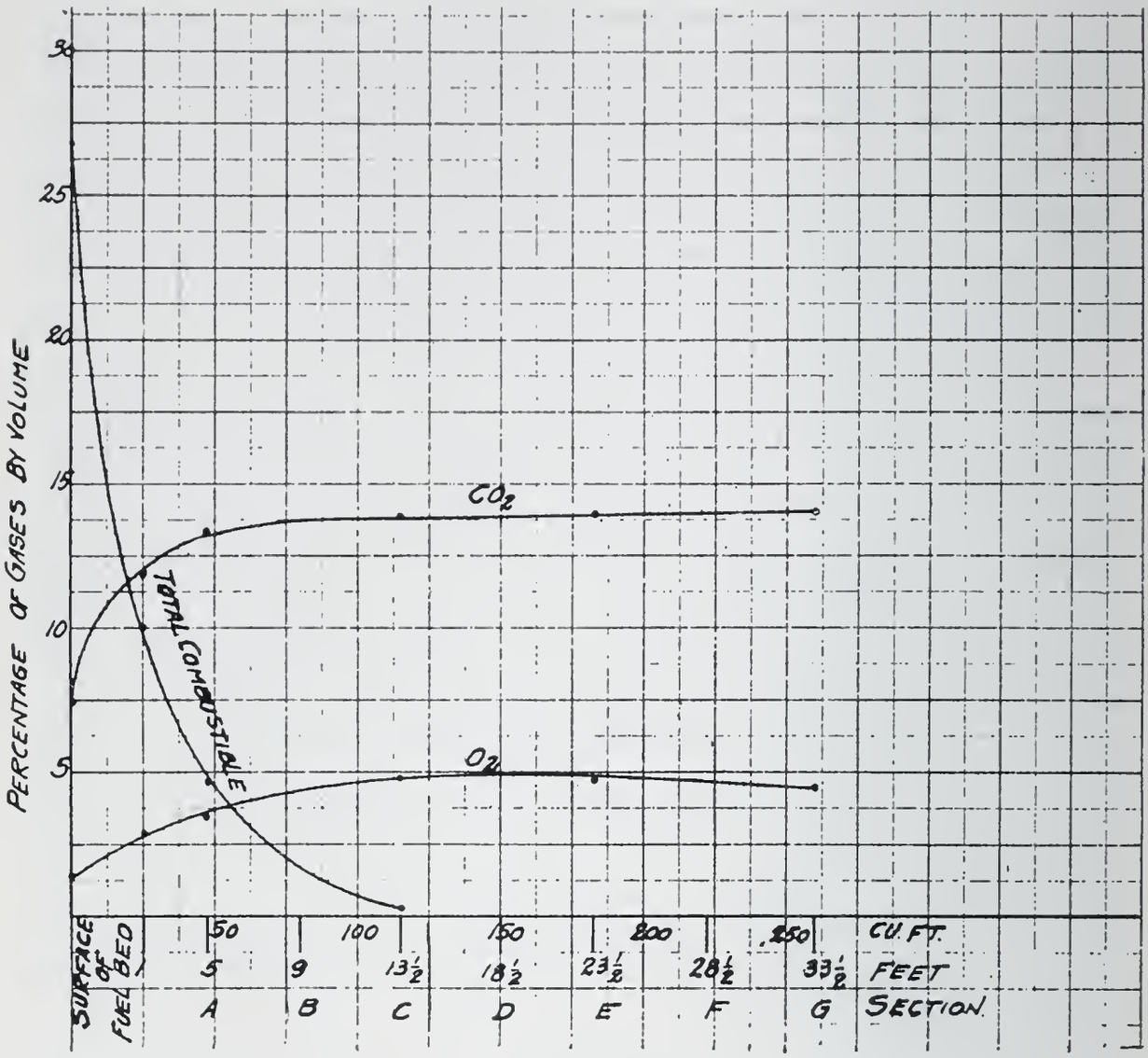

Fig. 2. Process of Combustion of Gases as Shown by Composition of Furnace Gases at Various Distances above Fuel Bed.

burgh screenings. The figure shows the process of combustion of the combustible gases rising from the fuel bed. The curve giving the percentage of total combustible gases is similar in shape to those shown in Fig. 1. The drop of the percentage of combustible at the beginning of the combustion process is not quite as rapid as shown by the curves of Fig. 1, because the air needed for the combustion was supplied a short distance above the fuel, as shown by the rising percentage of oxygen. If all the air were supplied immediately at the surface of the fuel bed and thoroughly mixed with the combustible gas, the drop of the percentage of combustible would have been much faster, and the curve would have been much more like those of Fig. 1.

Fig. 3 gives some experimental data obtained in an oil-burning furnace of a water-tube marine boiler equipped with Coen and Dahl

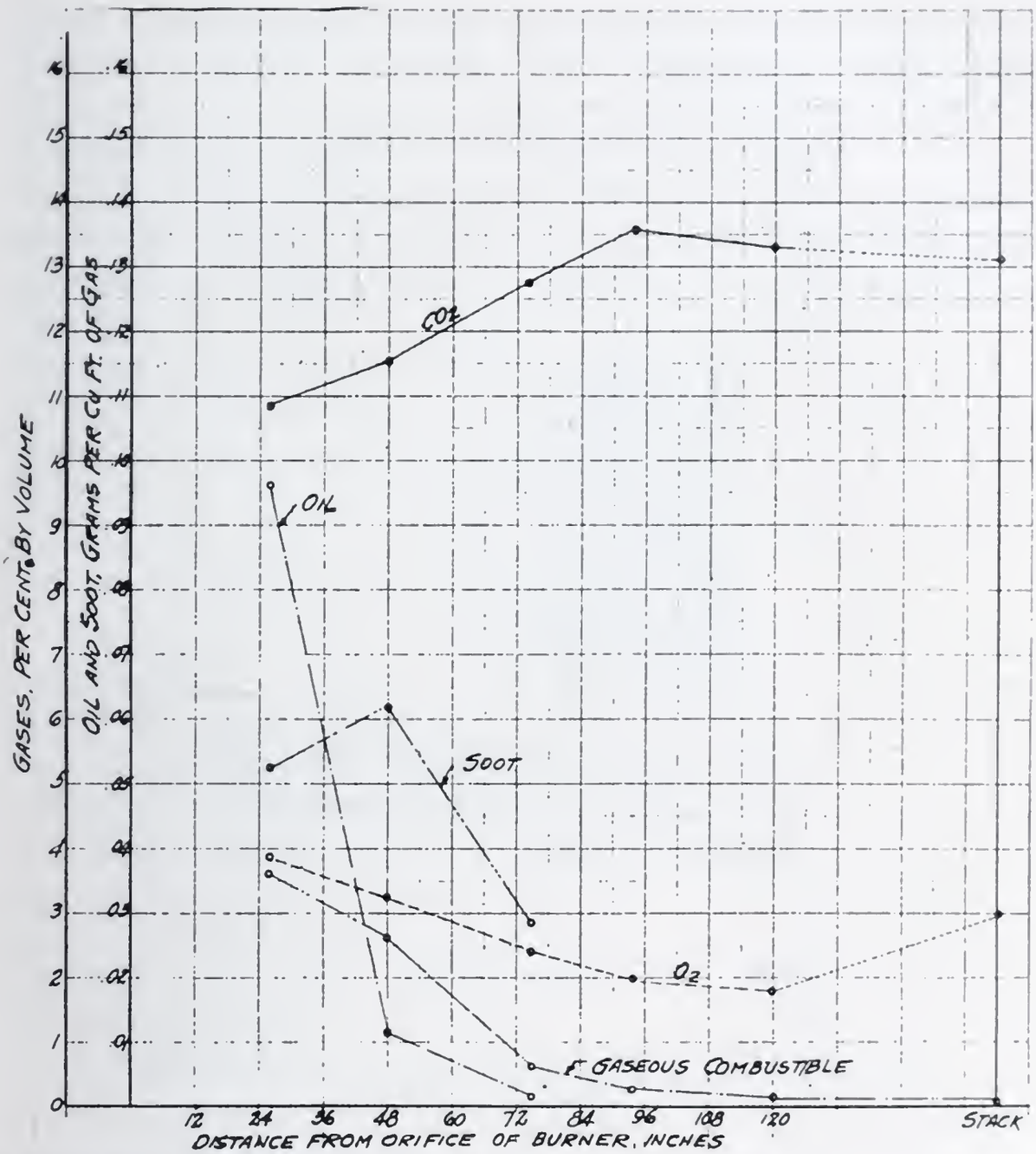

Fig. 3. Composition of Gases and Weight of Oil and Soot for Tests of Foster Burner.

burners. It is reproduced from Bulletin 214 of the United States Bureau of Mines. It shows the composition of gases and weight of oil and soot contained in the furnace gases along the path of the flame travel. The initial process in burning fuel-oil consists of partial combustion and partial breaking down of the oil into combustible gases and soot, which, in turn, burn as they come in contact with the oxygen necessary for their combustion. Apparently the rate of combustion is very high near the burners, the concentration of the combustible and oxygen is rapidly reduced and that of the CO_2 increased.

If the concentration of the total combustible were expressed on a common scale it is apparent that a curve giving such concentration would be similar to those given in Fig. 1.

Fig. 4 illustrates the probable arrangement of molecules in a homogeneous mixture of blast-furnace gas and air 20 per cent. in excess of that required for complete combustion. The figure is intended to show why time is required for the active molecules to make con-

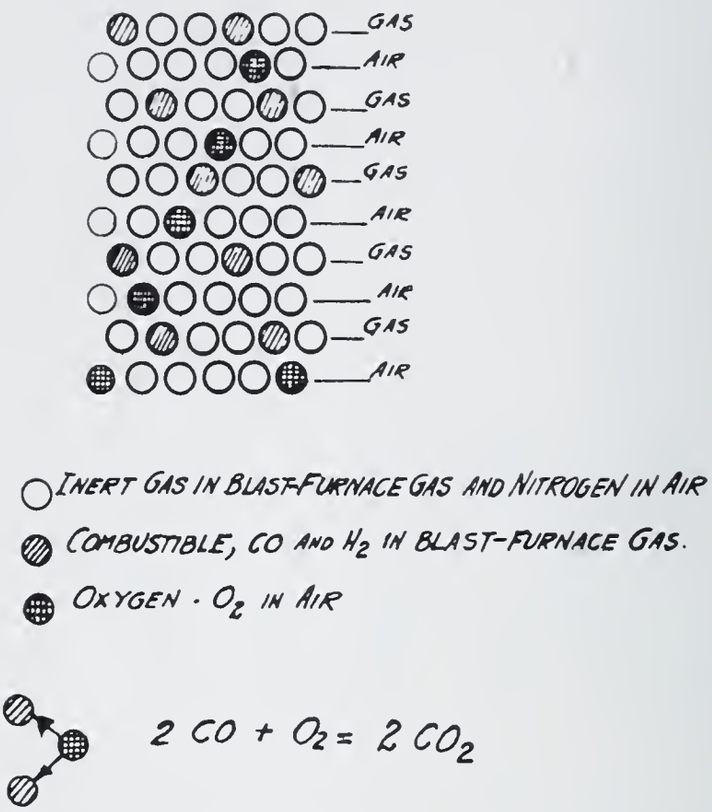

Fig. 4. Probable Arrangement of Molecules in Mixture of Air and Blast-Furnace Gas.

tact. Such a mixture can be obtained by alternate layers of blast-furnace gas and atmospheric air, each layer being one molecule thick. The gas is assumed to consist of one-third combustible (CO and H_2), and two-thirds inert gas (CO_2 and N_2). The air is assumed to contain one-fifth of oxygen and four-fifths of nitrogen. The excess air is represented by the light circles. The figure shows that only a few molecules of oxygen and of combustible are in position to make a direct contact. Most of the other molecules must move some distance before contacts can be made. The inert molecules are in their way and must be either moved out of the way, or the molecules of the oxygen and the combustible must move around them in order to make contacts. The combustible molecules that are near oxygen molecules

make contact first, and burn. As the process of combustion continues, more inert molecules are produced and fewer active molecules are left to make contact and to burn. The contacts occur less frequently and the process of combustion becomes slower.

When blast-furnace gas is burned under steam boilers the layers or streams of gas and air are three to four inches thick and the mixture produced by such layers or streams is far from homogeneous. The layers must travel a considerable distance through the furnace before the mixture becomes nearly homogeneous. As a result the rate of contact making between the active molecules is lower than shown by Fig. 1. Thinner layers and turbulence produce homogeneous mixture quickly. Turbulence in a uniform mixture causes the molecules to change their relative positions, and thus increases the rate of contact making between the active molecules.

Fig. 5 shows the probable arrangement of molecules in a combustible mixture of natural gas and air 20 per cent. in excess of that needed for complete combustion, and the probable reactions taking place in such a mixture. The mixture is shown to consist of a layer of methane a single molecule thick with layers of air six molecules thick on each side of the layer of methane. The figure is intended to illustrate how far the molecules of oxygen must move before they make contact with the molecules of methane. In a boiler furnace the layers are much thicker and the mixture is less homogeneous than shown in the figure and considerable turbulence is required in and near the burners to make the mixture nearly homogeneous. The rate of contact making and the rate of combustion are probably somewhat as shown by the curves of Fig. 1.

Conclusions. A definite volume of combustion space is necessary in all furnaces to give the combustible time to come in contact with oxygen and burn nearly completely before the furnace gases enter the boiler.

Intensive mixing, or turbulence, increases the rate of contact making between the combustible and the oxygen; therefore, if intensive mixing is permissible, the volume of combustion space can be decreased.

Intensive mixing, or turbulence, produces impingement of flame against furnace walls. When fuels containing ash are burned in fur-

naces with refractory walls impingement of flame causes excessive erosion of the furnace lining.

Furnaces with water-cooled walls permit impingement of flame; therefore intensive mixing can be used and high rates of heat liberation maintained.

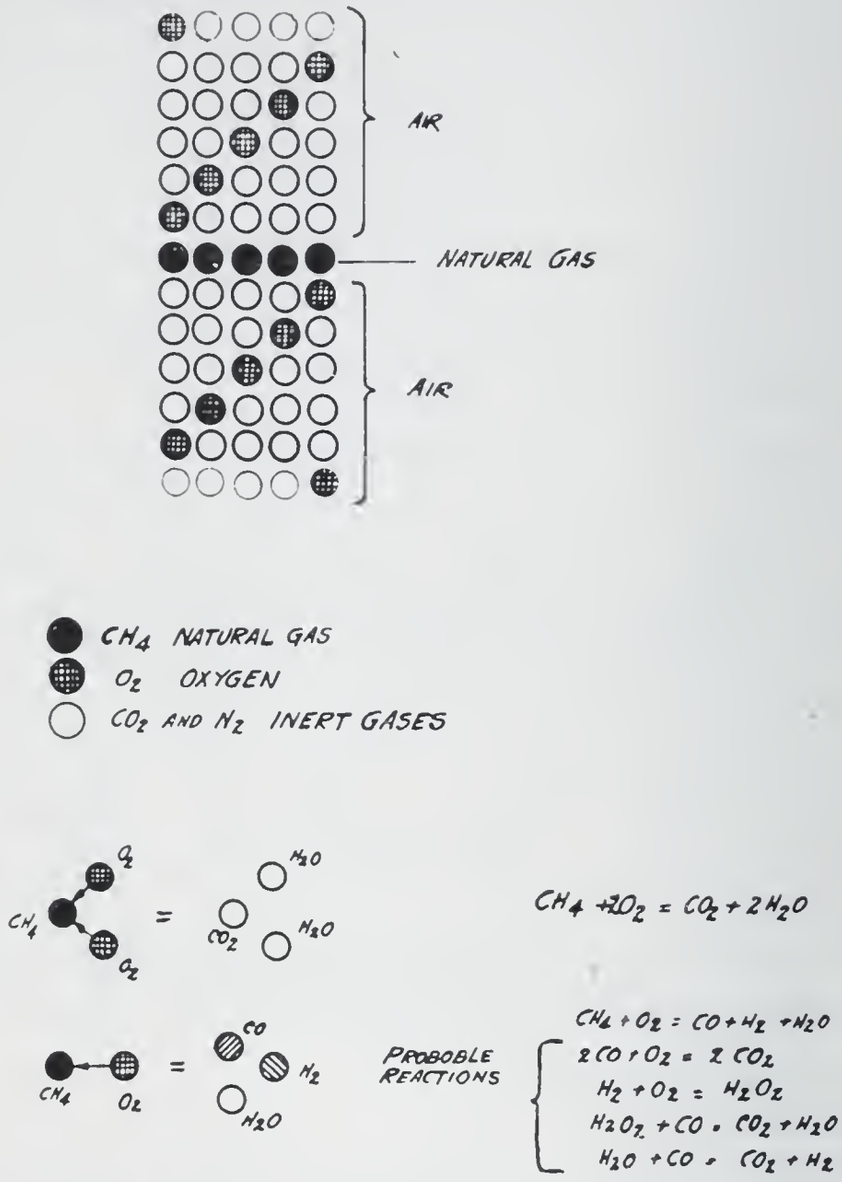

Fig. 5. Probable Arrangement of Molecules in Mixture of Air and Natural Gas.

The usual average rate of heat liberation in the combustion space with practically all fuels and all kinds of firing is between 10,000 and 30,000 B.t.u. per cubic foot of combustion space.

DISCUSSION

P. NICHOLLS:* Mr. Kreisinger finished his very interesting talk by emphasizing the necessity of providing the proper amount of combustion space. In Table I he lists the rates of heat liberation that are, or can be, used for each fuel. However, he does not give definite values, but allows a wide margin for each fuel and each type of apparatus (for example, 1 to 3 for natural gas and for fuel-oil); moreover, he gives the same margins both for normal operation and for maximum or peak-loads. It may be granted that such variations can be illustrated from operating plants and that they may illustrate poor and good design, and for the solid fuels may be partly necessary because of the differences in the fusibility of the ash. On the other hand, it does not seem reasonable that designers should differ so much in their ability to reduce the investment cost to the same figure. Can the author tell us how far designers are from the stage where they could determine the optimum combustion space for a given design and method of burning? Take fuel-oil, for example. What would a design based on 10,000 B.t.u. show in efficiency, financial balance, etc., as compared with a design based on 30,000 B.t.u.? What would be the plots of such factors against heat liberation, either normal or maximum, and how could one convince a customer that a proposal submitted will give optimum results?

The question amounts to asking if the design of furnaces and boilers has reached the stage of being able to predict accurately the results which will be obtained. If this stage has not been reached, could the author tell us what investigations he considers necessary to supply the missing data, on combustion, for example, so that one could put on paper definite rules for computing the correct dimensions for the combustion space to go with a given type of design of furnace and burning equipment?

J. E. DUNN:† I should like to hear what Dr. Kreisinger has to say relative to a combination burner for blast-furnace gas and pulverized coal that admits the blast-furnace gas around the coal stream? If such a combination burner were used, what type of setting and

*Combustion Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.
†Steam and Combustion Engineer, Republic Iron & Steel Co., Youngstown, Ohio.

what location of burners would he recommend? Recommending the use of separate burners for burning pulverized coal and blast-furnace gas in the same combustion chamber, what arrangement of burners would be preferable? How can the value of the constant K in the author's formula for contact be expressed as 1 (unity) when it takes into account the fineness of fuel in caes of pulverized fuel and the affinity of oxygen for hydrogen and carbon monoxid in the case of blast-furnace gas, wherein there would be considerable variation? Coke-oven gas, for example, has a high percentage of hydrogen in it and the affinity of oxygen for hydrogen being very great we could expect better combustion with a poor mixture of air and coke-oven gas than we could with blast-furnace gas. In other words, I believe that in the problem of combustion there is more than mere contact to be considered. We should consider disassociation, the equilibrium point at which reactions are completed, and also the temperature as some chemical reactions (and all combustion involves exothermic chemical reaction) do not take place to the same degree at the same temperature or different temperatures. The law of mass action plays an influential part in any combustion. Considering the many factors that enter into the supposedly simple matter of combustion, I believe it difficult to develop a very accurate formula for the rate of combustion.

I believe the fact that blast-furnace gas is so dirty and contains such a high percentage of inert gases would make it very difficult to obtain high rates of combustion with a combination burner. Again, both fuels require different quantities of air for combustion, thereby making regulation more complicated.

If blast-furnace gas and pulverized coal were fired through separate burners on the same side of a furnace, would you recommend placing the burners for pulverized coal above or below the burners for blast-furnace gas? If located side by side I believe considerable intermixing would occur, resulting in poor combustion.

F. M. Van Deventer:* As maximum liberating rates for pulverized fuels, your chart indicated 14,000 B.t.u. for coal with low-fusion ash; 20,000 B.t.u. for high-fusion ash; and 24,000 B.t.u. for

*Mechanical Engineer, H. L. Doherty & Co., New York.

water-cooled walls. This would indicate that with water-cooled walls, as high a liberating rate may be used with low-fusion ash as with high-fusion ash, without slagging difficulty. This may be true so far as slagging on the walls is concerned, but, as you intimated in your paper, sometimes slagging in the boiler tubes occurs at lower heat-liberating rates than slagging on the walls.

Our experience, particularly with lignite and air-cooled walls, is that slag accumulates on the boiler tubes and hampers satisfactory operation at liberating rates below those which cause trouble at the furnace wall. While this may not be true for other types of boilers, am I not right in saying that in the case referred to, water-cooled walls would not be of material benefit so far as increasing the allowable heat-liberating rate is concerned?

J. C. Hobbs:* Dr. Kreisinger correctly states that the rate of combustion in pulverized-coal furnaces is limited by the formation of slag on the boiler tubes. This is becoming generally recognized. Without discounting his paper, may I call attention to another phase of the problem—the relative dimensions of the furnace with respect to the area, position and form of "cold surfaces."

The usual boiler installation combines two major engineering problems. First the generation of the heat, and second, the transmission of the heat throughout the heating surfaces into the water. The former can best be carried out under high temperatures; whereas, as has been mentioned, slag troubles are now limiting the temperature at which the products of combustion may be admitted to the tube surfaces. A good design will recognize these two factors and provide a very hot zone for the combustion with an intermediate cooling zone in which, through radiation, a sufficient amount of heat will be taken out of the gases to allow the gases and suspended slag to enter the tube banks below the temperature at which the slag will stick.

The so-called wet-bottom furnace with a system for removal of molten ash improves the combustion or heat-generating conditions. The use of cold surfaces in the side walls near the top of the furnace after combustion has been completed helps to attain the second conditions, while the proper arrangement of boiler-tube surface at the top

*Superintendent of Power, Diamond Alkali Co., Painesville, Ohio.

assists not only in attaining the second conditions but in preventing slag from bridging across the tube spaces. One of the simple improvements in boiler design consists of using wider spacing both vertically and horizontally in those tubes nearest the furnace. With the straight-tube boiler, a great improvement has been made by using alternate downwardly offset tubes in the bottom row in place of the straight tubes. A large number of the new stations, including some at 1400 pounds pressure, have adopted this design.

W. N. Flanagan, *Chairman*:* Dr. Kreisinger set me to making comparisons when he spoke of the gas-engine. Most of us are accustomed to think that fuel must burn very rapidly in a gas-engine. In a big gas-engine making 83-1/3 revolutions per minute (0.36 second per stroke), the ignition of the fuel starts on the preceding stroke so that it has probably the last quarter of the compression and at least the first tenth of the power stroke, or approximately 0.125 second to burn. In the case of many gas-fired boilers, the fuel hits the tubes about 0.1 second after it leaves the mouth of the burner. This again brings to mind that the burner in the case of blast-furnace gas is the most important factor in the design of the boiler combustion chamber.

For instance, there are several ordinary installations of boilers fired by blast-furnace gas which are liberating normally 25,000 to 32,000 B.t.u. per cubic foot per hour. That could be attributed only to the excellent burners giving a very high rate of turbulence with the gas being split into small streams. There are a number of other installations which have a stove type of burner that throws the gas into thick streams in which, as Dr. Kreisinger explained, it takes a long time for the molecules to come in contact, and therefore to get a high rating without a considerable percentage of combustible gases in the stack requires a large combustion chamber.

Thus far, I have been referring to clean and cold gas. Clean, hot gas and preheated air, judging from the single instance in my experience, enable still higher rates of combustion; but, with dirty gas, there is another factor. Under high rates of combustion with very hot gas or preheated air, we run into the question of sintering the flue-gas. At any rate, the boiler furnace presents just as hard a prob-

*Special Engineer, Carnegie Steel Co., Pittsburgh.

lem as the gas-engine in which the reactions are usually considered as occurring very rapidly.

HENRY KREISINGER: Regarding the points brought up by Mr. Nicholls I would reply as follows:

In the paper, the rates of heat liberation are given in ranges because in power-plant operation the rates are not uniform, but cover a definite range. This range usually covers the ratio of 1 to 3, or 1 to 4. In some cases for certain service such range may cover a ratio of 1 to 12. Thus, if a unit is required to produce 100,000 to 300,000 pounds of steam an hour with natural gas as fuel, the furnace is designed so that when the unit generates 100,000 pounds of steam the rate of heat liberation in the furnace is 10,000 B.t.u., and with 300,000 pounds of steam, the rate of heat liberation is 30,000 B.t.u. per cubic foot per hour. The paper gives the ranges for best operating conditions. The designer of a furnace is interested in the range. He wants to know what is the lowest and the highest rate of heat liberation that will give him good operating conditions.

The best range of the rate of heat liberation for natural gas is given as 10,000 to 30,000 B.t.u., although we may find furnaces operated at 50,000 or even 60,000 B.t.u. But if we go into such plants and look into the superheater chamber we will see flames indicating that the combustion has not been completed in the furnace, but extends into the boiler and the superheater. Such extended combustion generally raises the temperature of the superheated steam so that instead of getting 750 degrees F. we may get at times 850 degrees F. If we wish to avoid the fluctuation of the superheat we should design the furnace so that the combustion will be nearly completed by the time the gases enter among the boiler tubes. This is true of natural gas, blast-furnace gas and powdered coal. It is also true to a large extent of stoker-fired furnaces.

The proportioning of the furnace is a problem for a furnace designer. He must so design the furnace that, with a given range of working, the rates of heat liberation remain within the range of best operation of the furnace. If the range of the variation of load is too wide, the designer has to make special provision in the design of the furnace and burners so that the equipment can be operated over this wide range of variation of the load. He may either have to use a

large number of burners so arranged that with very low load on the unit some of the burners may be cut out completely and combustion carried on by the remaining burners. Or, if he uses few burners, such burners must be adjustable so that with the very low ratings he may reduce the air and fuel channels in the burner in order to permit the air and the fuel to enter the furnace at high velocity and produce sufficient mixing for proper combustion. For example, if a unit burning powdered coal is to generate steam over a range extending from 25,000 to 300,000 pounds of steam an hour it may be best to provide 12 to 16 burners and operate only about one-fourth of them when the unit is working at the lowest rate of steam generation. To burn coal nearly completely for generating 300,000 pounds of steam requires a large furnace. If at this high load the rate of heat liberation is 30,000 B.t.u. per cubic foot of combustion space this rate would drop to an average of 2500 B.t.u. when the rate drops to 25,000 pounds of steam an hour. At this low rating, better combustion can be obtained if only a few of the burners are kept in operation. The burning is localized in a part of the furnace and the air can be admitted at high enough velocity to produce sufficient mixing for combustion. If at this low rating all burners were kept going, the air would have to be admitted over an extended area and would enter at low velocity that would not give good mixing. If large adjustable burners are used it may be desirable to shut down one-half of the burners and reduce the area on the remaining ones so as to make the air enter the furnace at high velocity, thus producing good mixing.

Good combustion requires mixing. Mixing means changing of relative position of the oxygen molecules and the combustible in whatever form the latter may be. Changing of relative position requires energy which must be supplied in some form. When gas or pulverized coal is burned, this energy is supplied in the form of kinetic energy; that is, the fuel and the air needed for combustion are supplied at high velocities. If there is to be rapid change of position, or intensive mixing, the stream of fuel and air should enter the furnace in different directions. Parallel flow does not produce good mixing.

When, at very low rating, only a part of the burners are kept in operation the combustion is confined to a part of the furnace where the mixing and the rate of heat liberation can be maintained at the minimum necessary for good combustion.

As to Mr. Dunn's first questions it may be said that as a rule it is better to burn blast-furnace gas and pulverized coal separately, as far as possible. Blast-furnace gas is a lean fuel and therefore requires a comparatively small quantity of free oxygen for its complete combustion. On the other hand, powdered coal is very concentrated fuel and requires a large quantity of free oxygen for combustion. If the two fuels are burned separately, one on each side of the furnace, the supply of air to each fuel can be more accurately regulated, and the products of combustion from one fuel do not dilute the combustible mixture of the other fuel.

If the distance between the front and rear walls exceeds about 14 feet the burners for the two fuels can be placed in the two opposite walls. If this distance is less, it may be advisable to locate the burners for both fuels in the same wall.

Good combustion results can not be expected with a mixture of blast-furnace gas and powdered coal. The gas would surround the coal particles and interfere with the free oxygen making contact with volatile matter distilled from the coal. As soon as the coal is heated the volatile matter comes off largely in the form of heavy tar vapors. If these tar vapors do not come quickly in contact with sufficient amount of free oxygen to burn them, they break down by the heat into soot and light combustible gases such as methane, hydrogen, and carbon monoxid. Under such conditions the combustion process proceeds very slowly with dense smoky flame. If, on the other hand, the particles of coal are surrounded by free oxygen in sufficient quantity to burn the volatile matter as the latter is distilled off, the combustion process takes place quickly with little or no soot being formed. It is better to burn the coal without smoke than to allow the formation of smoke and then attempt to burn the smoke after it has been formed. Mixing blast-furnace gas with powdered coal makes it difficult to concentrate enough free oxygen near the coal particles to produce quick and smokeless combustion.

In regard to the best location of burners in a furnace burning blast-furnace gas and powdered coal, it may be said that as a general rule the burners should be located so that the path of gases from the burners through the furnace is as long as possible. The second consideration is the space available for gas and air ducts and other mechanical problems. Usually the best arrangement is obtained if the coal

burners are placed in the front wall and the gas-burner in the rear wall opposing the coal burners. In such an arrangement the coal pipes and the air ducts leading to the coal burners will not interfere with the gas ducts and the air supply to the gas-burners. In cases where the distance between the front and rear walls of the furnace is too short for opposed firing, both the gas-burners and coal burners may have to be placed in one wall, keeping the two kinds of burners as far apart as possible so that the burning of the gas can not interfere with the burning of the coal. The gas burners can be located either below the coal burners or above them, depending on which arrangement will make a simpler lay-out of the piping supplying gas, air, and coal.

Another question was how to determine the constant K in equation (3). The answer to this question is left for experimental work. Experimental results now available and the observations of well-operated furnaces indicate that the constant is about 1. The value of the constant depends largely on the rapidity of mixing. With very intensive mixing, the constant is less than 1. With slow mixing it is greater than 1. The equation was presented to show (with a given intensity of mixing) the high rate of combustion near the burner as compared with the rates farther away from the burner.

The equation for the rate of contact making is directly applicable to burning of gases. In such cases both the combustible and the oxygen are in molecular subdivision and their concentration can be expressed in percentage by volume. When it comes to the burning of powdered coal there is no common basis to express the concentrations. The oxygen is in a gaseous state, whereas the coal exists in comparatively very large masses in a solid state and therefore it is not possible to express its concentration in percentage by volume. As the fineness of pulverization increases, the masses of the solid coal become smaller. The smaller particles can be better dispersed through the air so that the oxygen molecules do not have to travel as far to make a contact as when the particles are large. The smaller particles of coal also present a much greater surface than the large particles for the contacts with oxygen. Perhaps one way of expressing the concentration of coal would be to give it in the extent of the surface of the coal particle per cubic inch or per cubic foot. There is no doubt that the fineness of pulverization increases the rate of contact between the coal particles and the oxygen molecules. Whatever the fineness of pulver-

ization of the coal may be the curves of Fig. 1, when applied to coal, indicate the relative rate of contact making and also the rate of combustion along the path of the mixture through the furnace. The rate is high near the burner where the concentration of the reacting substances is high, and is low far away from the burner where this concentration is low.

Mr. Dunn mentions several other factors which in his opinion should be considered in the process of combustion—namely, the affinity of oxygen and hydrogen and other combustibles, dissociation, the equilibrium point, chemical reactions, temperature, and mass action. When we limit our discussion to the process of combustion in boiler furnaces some of these factors are either eliminated or their effects are so reduced that they may be disregarded.

Affinity is a very indefinite term. Most chemists and physicists avoid using it. It has been inherited from the old alchemists who mere more interested in the question of why instead of how changes took place.

In the boiler furnace the temperature is too low for dissociation of products of combustion to take place to any measurable extent. It takes very high temperatures to dissociate a small fraction of one per cent. of water vapor into hydrogen and oxygen. We may, therefore, leave dissociation out of consideration. In all boiler furnaces the equilibrium point is reached when the concentration of combustible is reduced to zero, because we should always have enough oxygen in the furnace for complete combustion. The chemical reaction and the temperature go together. The higher the temperature the more rapidly the chemical reaction takes place. At the ordinary furnace temperatures the chemical reaction may well be regarded as instantaneous.

The law of mass action is really the concentration of the reacting substances in the mixture, and is the most important factor in the process of combustion in a boiler furnace.

The process of combustion in a boiler furnace is principally a chain of two consecutive processes. The first link or process of this chain is the bringing of oxygen and combustible in contact. The second process or link in the chain is the chemical combination of the oxygen with the combustible. The speed of combustion is always controlled by the slower of the two links of the chain. The process of bringing oxygen and combustible in contact is by far the slower of the

two links. It takes time to bring oxygen and combustible together to make contact. Once they are brought in contact the chemical combination is virtually instantaneous. This is the reason why the equation given in the paper was made to express the rate of contact instead of the rate of chemical reaction. High rates of combustion are accomplished by intensive mixing. In all cases where high rates of combustion were obtained it was accomplished by taking the fullest advantage of turbulence; that is, by bringing oxygen and combustible quickly together.

As a rule, when blast-furnace gas is burned, better mixing and better combustion can be obtained if the gas and the air are supplied in small streams through narrow slots. This brings the oxygen quickly in contact with the combustible; but in designing and operating such burners a limit is soon reached on account of the dust contained in blast-furnace gas. This dust settles in the burners and requires frequent removal. Burners with small slots could not be cleaned easily. Natural gas is clean, and some of the natural-gas burners on the market have the gas slots 0.5 inch long and 0.01 inch wide. Such burners produce very favorable conditions for good combustion.

The remarks of Mr. Van Deventer and Mr. Hobbs regarding the limit to the rate of heat liberation with pulverized coal in a water-cooled furnace, are correct. The limit is more frequently established by the slagging of the boiler than by the slagging of the furnace walls. If the coal has very fusible ash the upper limit may be lower than that given in the table; with coals having comparatively non-fusible ash the limit is higher. The extreme high limit of 40,000 B.t.u. is for short peak-load periods. By the time the slag accumulation on the boiler tubes reaches a condition which will seriously affect the flow of gases through the boiler, the peak-load period is over, and the rating reduced. The slag accumulation on the tubes is then removed during the low-load or banking period.

As to the slagging of boiler tubes when lignite is burned in air-cooled furnaces, it is likely that a water-cooled furnace would permit higher rates of heat liberation, because the gases and the molten particles of ash would be cooled to some extent by the water wall before the ash reached the boiler tubes. This would be particularly true of the uncovered types of water walls.

ANNUAL MEETING—CIVIL SECTION

The annual meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Monday evening, January 8, at 8:10 o'clock, Chairman C. S. Davis presiding, 114 members and visitors being present.

The minutes of the last meeting, held November 22, 1928, were read and approved.

The annual report of the Section was read by the Chairman.

The report of the Nominating Committee was presented by the Assistant Secretary, as follows:

To Officers and Members, Civil Section:

DEAR SIRS—Your Nominating Committee, appointed to nominate officers for the Civil Section for the ensuing year, met today and nominated the following:

J. F. Laboon.....Chairman
E. E. Lanpher..... Vice Chairman
C. N. Haggart
N. B. Jacobs
F. S. Merrill
H. P. McKown
L. J. Riegler
.....Directors

Respectfully submitted,
R. P. FORSBERG, *Chairman,*
V. R. COVELL,
RICHARD KHUEN, JR.,
Nominating Committee.

On motion, nominations were closed and the Secretary requested to cast a unanimous ballot for the nominees, who were thereupon declared elected.

J. F. Laboon, the Chairman-elect, then took the chair.

The following papers were then presented: "Precast Concrete Piles and Special Equipment for Handling and Placing," by Maxwell M. Upson, and "The Importance of River Terminals and Docking Facilities in the Development of River Transportation," by E. K. Morse.

The ensuing discussion was participated in by: C. M. Reppert, A. E. Crockett, T. M. Rees, C. S. Davis, Edward Godfrey, C. L. Riegel, A. E. Boardman, C. N. Haggart, P. W. Price, and P. R. Tarn.

The meeting adjourned at 10:50 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor E of the William Penn Hotel, Tuesday afternoon, January 22, 1929, at 4 o'clock, Vice President J. N. Chester presiding in the absence of President J. A. Hunter, Messrs. W. L. Affelder, V. R. Covell, W. E. Fohl, A. Pinkerton, L. O. Lougee, W. B. Skinkle and L. C. Edgar being present, Messrs. G. E. Dignan, H. N. Eavenson, T. J. McLoughlin, G. T. Ladd, J. F. Laboon, A. S. Davison and A. Stucki being absent.

The minutes of the last regular meeting, held December 18, 1928, were approved without reading.

Applications from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBER

Mylrea, T. D.

ASSOCIATE

Freeman, H. R.

JUNIORS

Cunningham, D. S. Sommerfield, E. M.
Straub, D. B.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Boardman, C S. Hulse, A. J.
Fox, C. A. MacLachlan, R.
Gregg, L. O.

ASSOCIATE MEMBERS

Edstrom, E. H. Lassman, B.

ASSOCIATE

Gealy, E. J.

JUNIOR

Mackenzie, J. J. P.

An application for transfer was received from Philip S. Wickerham, and after discussion he was transferred to the grade of Member.

Resignations were received from the following, and after discussion they were accepted: M. L. Ilfeld, C. E. Johnson, W. D. Lowe, J. F. Munn, E. C. Peirce, L. M. Sandston, H. C. Siebert, Charles Schley, G. Sutherland and Theron Wasson.

The Secretary reported the following deaths: J. H. Offutt, joined Society October, 1915; died June 24, 1928. E. O. Mueller, joined Society March, 1921; died December 20, 1928. G. T. Swarts, joined Society February, 1914; died December 27, 1928. E. J. Taylor, joined Society February, 1903; died December 24, 1928.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 217 during the month of December, 1928.

Attention was called to the fact that during the illness of Mr. Davison, W. B. Spellmire, past President and past Chairman of the Entertainment Committee, had stepped in and rendered great assistance in securing speakers. It was regularly moved and carried that the Secretary be instructed to write Mr. Spellmire, expressing the appreciation of the Board for his co-operation in assisting us in assuming the responsibilities of the Chairman of the Entertainment Committee.

Mr. Affelder, Chairman of the Membership Committee, reported that the Committee held one meeting to go over applications received sinc the last meeting of the Board and to act on any other business coming before the Committee.

The Secretary presented a letter from C. B. Gerber, a member in good standing of the Detroit Enginering Society, requesting that in accordance with our reciprocity arrangement with the Detroit Society his membership be transferred to the Engineers' Society of Western Pennsylvania. The Secretary reported that he had communicated with the Detroit Society and found

that Mr. Gerber's dues were paid to December, 1928. It was regularly moved and carried that Mr. Gerber be transferred to membership in the Engineers' Society of Western Pennsylvania.

C. S. Davis called attention to the fact that inasmuch as this is the last meeting he will attend as a member of the Board, and that as he was serving as Chairman of a special committee having to do with a building code for welding, he would like to ascertain whether or not the Board wanted him to continue as Chairman and whether they desired the Committee to continue this work. Mr. Chester stated he would appreciate having Mr. Davis act as Chairman of this Committee, as previously recommended.

Mr. Chester stated that beginning with the next meeting of the Board he would be very glad to have suggestions from members as to any change in policy advisable during the coming year. Mr. Affelder raised the question regarding the time of Board meetings, stating that he felt it possibly would be more convenient for the members in general if the meetings were held at 1 o'clock, rather than at 4. The Chairman stated he was glad to receive this suggestion and would give it further consideration at a later meeting.

The meeting adjourned at 5:30 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING

The forty-ninth annual meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room of the William Penn Hotel, Tuesday, January 22, at 8:00 P. M., President John A. Hunter presiding, 105 members and visitors being present.

The minutes of the last annual meeting, held January 17, 1928, were read and approved.

The annual report of the Board of Direction, including the reports of the Standing Committees, the Sections and the Treasurer, was read as follows:

REPORT OF BOARD OF DIRECTION

During the year ten meetings of the Board of Direction were held, at which the routine business of the Society was transacted.

Seven regular meetings and the annual meeting of the Society were held this year, with the total attendance of 885. Papers and discussions were given at each of these meetings.

The policy of the Society, in regard to its meetings, has been changed during the last two or three years by the substitution of all-day conferences for the evening meetings of the Sections and the popular lecture course, started this year, to take the place of our regular monthly meetings. These changes were made after considerable thought by the Chairman and Committees of the Sections, and the general Society and the Board will appreciate comments, either favorable or unfavorable, from the membership regarding this change. It is only from your comments that we can judge whether or not we are giving you those activities and services which you desire.

The attendance of members making use of our Club Room is still increasing, and we hope that during the coming year many more of our members will avail themselves of the facilities of our organization.

Respectfully submitted,

K. F. Treschow, *Secretary.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Entertainment Committee begs to submit the following report on the social activities during the past year:

Annual Banquet—January 28. Attendance 1203.

Inspection Trip to Detroit—May 28. Attendance 38.

Inspection Trip, Heppenstall Forge and Knife Company—November 23. Attendance 84.

Annual Open House—February 24. Attendance 99.

Ladies' Night Party—April 11. Attendance 96.

Halloween Party—October 27. Attendance 75.

Election Night Party—November 6. Attendance 80.

Boat Excursion—June 21. Attendance 200.

Bridge and Chess Tournaments were held as usual.

A dinner was held on November 23, in honor of the American Engineering Council, which held a two-day meeting in Pittsburgh. Attendance 35.

The Entertainment Committee and Board of Direction have had considerable discussion in connection with our social activities and it is hoped that

if the membership desires the continuation of these activities they will give them their support during the coming year. All of these social events have been conducted at a loss, and while the Board of Direction was glad to bear a certain amount of expense in connection with these events, they feel that the program must be curtailed unless there is a larger attendance in the future. The Committee would appreciate written comments from the membership as to whether or not these Ladies' Night Parties, particularly, are desirable activities to continue.

Respectfully submitted,

A. S. Davison, *Chairman.*

REPORT OF FINANCE COMMITTEE

To Members of the Society.

Dear Sirs:

Your Finance Committee has held several meetings during the year, at which the general financial condition of the Society was discussed, budget planned, receipts estimated, etc.

The receipts for the year 1928 were estimated at $23,834.80. Actual receipts were $23,182.50. Expenditures were estimated at $23,430.00, and actual expenditures were $24,885.00. The increase in the budget of expenditures was mainly due to $500.00 additional rent held over from December, 1927, and a deficit in two of the functions held by the Entertainment Committee due to unusual weather conditions.

At the beginning of 1928 we had on hand $3,176.01 in unpaid bills. At the end of the present year our unpaid bills amounted to $1,759.22, which means that we absorbed during the past year $1,416.79 of last year's deficit. In general, the finances of the Society are in better shape this year than last, but it can be seen from the above figures that a very careful study of our financial condition should be made during the coming year.

Respectfully submitted,

W. E. Fohl, *Chairman.*

REPORT OF HOUSE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

In presenting the annual report of the House Committee I wish to advise that we had an evening attendance of 5640 during the past year, an increase of 860 over the previous year.

The only addition to our equipment made this year by the Committee was the purchase of a ditto machine for use in the office.

The Committee has been in touch almost constantly during this year with both the former and present owners of the hotel with reference to quarters for the Society. Several plans were considered both in our present location and on the third floor of the new addition to the hotel. It was finally decided, after numerus meetings and a joint special meeting with the Board of Direction, to continue in our present location with certain improvements. It was felt by the Committee and the Board that the Society could not afford to move to an upper floor of the hotel, due to the inconvenience to which the members would be put in reaching our quarters. We have, we believe, secured a rearrangement of our present quarters which will make them much more attractive. This includes an additional room, which can be used as a conference room, new executive offices and a check room. A

new plan will give us about two hundred and fifty square feet additional space. The main Club Room will remain as at present, except that the entrance will be from the double door at the left of the room. We hope that the membership will approve the work of the Committee, as it has been rather difficult to reach a decision, in that we wish to give you the best that can be secured within our means and at the same time keep the quarters in a location which can easily be reached.

Respectfully submitted,

V. R. Covell, *Chairman.*

REPORT OF MEMBERSHIP COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

The Membership Committee held ten meetings during the past year for the transaction of its regular business.

Several plans for bringing the Society to the attention of the engineers in the district were inaugurated, with the result that 138 new members were elected during the year. The membership, as of December 31, 1928, was 1656, divided as follows:

Honorary Member	1
Members	1274
Associate Members	179
Associates	82
Juniors	110
Student Juniors	10
Total	1656

Changes during the year were as follows:

Dropped	118	Deaths	7
Resigned	39	Accessions	138

The assistance and co-operation of the members of the Committee is gratefully acknowledged.

Respectfully submitted,

L. J. Affelder, *Chairman.*

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Publication Committee begs to submit the following report on its work during the past year. Three meetings of the Committee were held during the year to arrange the program of meetings, an average of six members being in attendance.

Attendance at the meetings was the most important matter discussed by the Committee. Attention was called to the fact that the number of members attending the regular monthly meetings had been on the decline for some time and it was felt that a change of program was needed to stimulate new interest. In the spring of this year a letter was sent to the entire membership, calling their attention to the decrease in attendance and inviting their

co-operation in this problem by sending in suggestions as to the type of meeting in which they would be interested, together with recommendation as to day and time on which the meeting should be held. Thirty replies were received to this letter, and these were gone over very carefully by the Committee. After careful consideration of the entire problem it was decided to attempt a popular lecture course of four lectures, the details with which you are now acquainted.

It is rather difficult in an organization with a membership as large as ours to determine just the type of meeting in which the largest number will be interested, and the Committee will appreciate the comments of the members, either favorable or unfavorable, on this new venture. The attendance at the two lectures held seems to indicate that they are being very well received by the members. These two meetings have been the largest held by the Society for some time.

Respectfully submitted,

L. C. Edgar, *Chairman.*

REPORT OF TREASURER

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Treasurer desired to submit the following report for the year 1928 as follows:

RECEIPTS

Dues Collected	$20,477.46
Entrance Fees	625.00
Sale of Advertising Space	5,740.72
Sale of Magazine Proceedings	262.92
Sale of Society Pins	107.00
Interest on Bonds	1,275.00
Interest on Bank Balances	195.67
Income from Banquet	8,295.00
Income from Open House Party	227.50
Ladies' Night Party	96.00
Sales of Boat Excursion Tickets	366.00
Inspection Trips	880.72
Golf Tournaments	571.30
Halloween Party	96.00
Joint Meetings	83.25
All-Day Conferences	301.50
Enrollments to Lecture Course	501.50
American Engineering Council Dinner	104.00
Refund on Proceedings Cuts	105.93
Sale of Printed Matter	58.68
Sale of Waste Paper	10.51
Total Receipts	$40,381.66

DISBURSEMENTS

Administrative in General	$20,415.18	
Cost of Magazine PROCEEDINGS	4,372.86	
Furniture and Fixtures	130.02	
Bonds Purchased	1,454.03	
Open House Party	578.60	
Ladies' Night Party	245.42	
Detroit Inspection Trip	1,267.00	
Halloween Party (1927)	121.00	
Boat Excursion	752.47	
Golf Tournaments	764.29	
Halloween Party (1928)	178.90	
Sundry Other Entertainments	712.13	
Sectional Expense	2,605.03	
Annual Banquet	7,218.86	
Annual Banquet (1929)	395.30	
Total Expenditures	$41,211.09	
Less Bond Investment	1,454.03	
		39,757.06
Excess of Receipts over Expenditures		$ 624.60
Less Entrance Fees		625.00
		$ .40

CASH ASSETS

	December 31 1927	December 31 1928
Permanent Fund (Bonds)	$20,282.50	$21,885.00
Cash (Fidelity Title & Trust Company)	849.54	825.51
Reserve Fund:		
Cash (Fidelity Title & Trust Company)	2,500.00	2,500.00
General Fund:		
Cash (First National Bank)	269.10	13.70
	$24,651.14	$25,224.21

BOND INVESTMENTS

2 Connellsville Water Co. 5 per cent., 40-year Gold Bonds, Nos. 317-18, maturing October 1, 1939	$ 1,930.00
3 Follansbee Bros. Co. 1st Mtge., 5 per cent., S. F. Gold Bonds, Nos. 788-9-90, maturing June 1, 1947	2,970.00
2 Jamison Coal & Coke Co. 1st Mtge., 5 per cent., S. F. Gold Bonds, Nos. 1502-3, maturing May 1, 1931	2,000.00
3 First Mtge. Jones & Laughlin Steel Co., 30-year, 5 per cent. Gold Bonds, Nos. 3020, 3021 and 3022, maturing May 1, 1939	3,150.00
2 Portsmouth, Berkeley & Suffolk Water Co. 40-year Gold Mtge. Bonds, 5 per cent., Nos. 465 and 466, maturing November 1, 1944	1,980.00
2 Shell Pipe Line Corp. 25-year., S. F. Gold Debenture Bonds, 5 per cent., Nos. 9721-24129, maturing November 1, 1952	1,935.00
4 Spang, Chalfant & Co. 1st Mtge., S. F. Gold Bonds, 5 per cent., Nos. 4593-4-1596-1600, maturing January 1, 1948	3,920.00
4 Wheeling Steel Corp. 1st Refg., S. F. Mtg. Bonds, 5½ per cent., Nos. 8518-9 and 533-4, maturing July 1, 1948	4,000.00
	$21,885.00

Respectfully submitted,

A. STUCKI, *Treasurer.*

REPORT OF CIVIL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Civil Section respectfully submits the following report on the work of the Section for the year 1928:

Three meetings of the Executive Committee were held during the year for the arrangement of meetings for the Section.

An all-day conference was held on November 2, 1928, at which the general subject of "Welding" was discussed. There was an attendance at this meeting of 216.

Two evening meetings were held during the year, one being the annual meeting, the attendance at these two meetings being 143.

The Committee believes from our experience this year that the all-day conference proves more attractive to the membership than the evening meeting.

Respectfully submitted,

J. F. LABOON, *Chairman.*

REPORT OF ELECTRICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

Your Executive Committee wishes to report on work done by the Electrical Section during the year 1928 as follows:

Eight regular meetings and two dinner meetings were held during the year, with a total attendance of 2137.

Papers and discussions were presented at each of these meetings.

One meeting of the Executive Committee for the discussion of program was held.

All of the above-mentioned meetings were held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers.

Respectfully submitted,

A. PINKERTON, *Chairman.*

REPORT OF ILLUMINATING ENGINEERS' SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Illuminating Engineers' Section begs to report as follows on work done by the Section during the year 1928:

Two meetings of the Illuminating Engineers' Section of the Society were held during the year 1928, with a total attendance of 78.

Several meetings of the Executive Committee were held for the discussion of the regular business of the Section.

Both of the meetings referred to above were held jointly with the Pittsburgh Section of the Illuminating Engineering Society.

Respectfully submitted,

L. J. KIEFER, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Mechanical Section wishes to report on work accomplished during the year 1928 as follows:

Four meetings of the Executive Committee were held during the year to arrange a program for the season 1928-1929.

Two all-day conferences were held, one on April 3, 1928, and one on October 22, 1928, with a total attendance of 429.

One evening meeting, being the annual meeting of the Section, was held, with an attendance of 106.

The Committee believes that the experience of the last two years has shown that it is desirable to cut down on the evening meetings and hold in their stead all-day conferences. The attendance at the all-day conference has more than doubled over the evening meeting and the discussions presented are more in number, due to the increase in time available during the meeting for oral discussion.

Respectfully submitted,

G. E. DIGNAN, *Chairman.*

REPORT OF MINING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Mining Section submits the following report on the work of the Section during the past year:

Four meetings of the Executive Committee were held for the purpose of arranging programs for the various meetings of the Section.

Two all-day conferences were held during the past year, one on April 12, 1928, and the other November 26, 1928, the total attendance at these two meetings being 292.

The annual meeting of the Section was held on March 27, 1928, with an attendance of 150.

As a result of the all-day conference held April 12, at which the subject of "Design and Operation of Electrical Equipment for Gaseous Mines," with special reference to "Motors and Their Control," was presented, a Special Committee was appointed by the Chairman to prepare a code of standards for approved electrical equipment for gaseous mines. This Committee has held several meetings and is now preparing this code. A final report will be presented by the Committee at an all-day conference to be held in April this year.

Respectfully submitted,

L. O. LOUGEE, *Chairman.*

REPORT OF PRACTICING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Practicing Engineers' Section begs to submit the following on work accomplished by the Section during the past year:

Two meetings were held, one being the annual meeting, with a total attendance of 38, and the other being a regular meeting, with an attendance of 14.

Matters of importance to the membership were discussed at both of these meetings and several committees appointed, which are to report during the coming year.

Respectfully submitted,
G. F. SIEFERS, JR., *Chairman.*

REPORT OF STEEL WORKS SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The Executive Committee of the Steel Works Section begs to submit the following report:

Five meetings of the Executive Committee were held during the year. Due to unfortunate circumstances, the two all-day conferences scheduled by the Committee for the year 1928 were abandoned. However, plans have already been made for two all-day conferences and two evening meetings during the coming year.

Respectfully submitted,
W. B. SKINKLE, *Chairman.*

REPORT OF THE TELLERS

To the Members of
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

In accordance with Section IX, Article V, of the By-Laws of our Society, your tellers, appointed by the President, publicly canvassed the ballots in the election of officers at noon, Tuesday, January 22, 1929, and wish to report as follows:

Total ballots counted		497
For President	J. N. Chester	486
For Vice President	L. C. Edgar	497
For Treasurer	A. Stucki	496
For Directors	C. E. Lesher	494
	W. B. Skinkle	493

Respectfully submitted,
J. S. FULTON, *Chairman,*
WILLIAM SHAW,
W. F. SANVILLE,
Tellers.

The President thereupon declared the following gentlemen elected:

President .....J. N. Chester
Vice President.....L. C. Edgar
Treasurer ..... A. Stucki
Directors..... { C. E. Lesher
W. B. Skinkle

Past Presidents George H. Neilson and W. E. Fohl escorted the President-elect to the chair.

No further business coming before the Society, the address of the retiring President was presented by John A. Hunter, Assistant Chief Engineer, American Sheet & Tin Plate Company, Pittsburgh, on "Development of the Continuous Pack Heating Furnace."

On motion, the meeting adjourned at 10:00 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—STEEL WORKS SECTION

The annual meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room of the William Penn Hotel, Tuesday evening, January 29, at 8 o'clock, Chairman W. B. Skinkle presiding, 107 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Chairman was submitted.

The report of the Nominating Committee was presented by the Secretary as follows:

"*To Officers and Members, Steel Works Section.*

Gentlemen—Your Nominating Committee appointed to nominate officers for the ensuing year met today and nominated the following:

B. R. Shover .....Chairman
S. S. Wales .....Vice Chairman
Louis Ellman
D. D. Pendleton
C. M. Johnson
W. Whigman, Jr.
L. Stone
.....Directors

Respectfully submitted,

G. D. Bradshaw, *Chairman,*
William Shaw,
R. E. Butler,
Nominating Committee."

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot for the officers named, and they were thereby declared elected.

No further business coming before the Section, the paper of the evening, on "Purchasing Public Utility Energy for Industrial Use," was presented by W. B. Skinkle, Engineer, Pittsburgh District Power Committee, Subsidiary Companies of United States Steel Corporation.

The ensuing discussion was participated in by: B. R. Shover, Consulting Engineer, Pittsburgh; E. D. Dreyfuss, Engineer, West Penn Power Co.,

Pittsburgh; G E. Stoltz, Manager Industrial Engineering, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.; W. E. Moore, President, Pittsburgh Electric Furnace Co., Pittsburgh; F. M. Van Deventer, Mechanical Engineer, H. L. Doherty Co., New York City; G. W. Ousler, Assistant Electrical Engineer, Duquesne Light Co., Pittsburgh; D. E. Cutler, Compressor Specialist, General Electric Co., Pittsburgh; A. R. Simpson, Engineer, Pittsburgh Electric Furnace Co.. Pittsburgh; and J. W. Bates, Steam Engineer, American Sheet & Tin Plate Co., Pittsburgh.

On motion, a vote of thanks was extended to Mr. Skinkle for his very interesting paper.

The meeting adjourned at 10:40 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—MECHANICAL SECTION

The annual meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held Thursday evening, February 14, at 8:00 o'clock, in the Blue Room of the William Penn Hotel, Chairman G. E. Dignan presiding, 57 members and visitors being present.

The minutes of the last annual meeting, held February 7, 1928, were read and approved.

The report of the Nominating Committee was read by the Chairman as follows:

"*To Members and Officers of Mechanical Section,*

Engineers' Society of Western Pennsylvania.

Dear Sirs—In accordance with the By-Laws of the Section, your Nominating Committee, appointed by the Chairman, has met and respectfully submit the following members as nominees for the offices of the Section for the coming year:

Chairman.....C. A. Carpenter

Vice Chairman.....H. G. McIlvried

Directors..... { W. P. Chandler, Jr.
R. M. Overton
T. E. Purcell
W. N. Flanagan
H. M. Hallett

Respectfully submitted,

E. P. Dandridge, *Chairman,*

D. E. Cutler,

T. J. Barry,

Nominating Committee."

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named, who were thereupon declared elected.

The Chairman-elect, C. A. Carpenter, then took the chair.

No further business coming before the Section, an address by the retiring Chairman, G. E. Dignan, was presented on "Mechanical Equipment for the Davison Coke & Iron Company at Neville Island." The ensuing discussion was participated in by: A. P. Myers, Vice President, Davison Coke & Iron Co., Pittsburgh; W. W. Boyd, Chief Engineer, Standard Scale & Supply Co., Beaver Falls, Pa.; and J. S. Green, Master Mechanic, Edgewater Steel Co., Oakmont, Pa.

On motion, the meeting adjourned at 9:30 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor C of the William Penn Hotel, Tuesday afternoon, February 19, at 4:00 o'clock, President J. N. Chester presiding; Messrs. W. L. Affelder, L. C. Edgar, B. R. Shover, W. B. Skinkle, C. E. Lesher, G. T. Ladd, J. F. Laboon, L. J. Kiefer, C. A. Carpenter, L. O. Lougee and G. F. Siefers being present, and Messrs. V. R. Covell, T. J. McLoughlin, J. A. Hunter, A. Stucki, A. S. Davison and A. C. Fieldner being absent.

The minutes of the last regular meeting, held January 22, were approved without reading.

Applications from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Boardman, C. S.
Fox, C. A.
Gregg, L. O.
Hulse, A. J.
MacLachlan, R.
Robertson, A. W. (by invitation)

ASSOCIATE MEMBERS

Edstrom, E. H.
Lassman, B.

ASSOCIATE

Gealy, E. J.

JUNIOR

Mackenzie, J. J. P.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Allewelt, Robert
Andrews, J. R.
Cary, E. F.
Connar, V. N.
Dalbey, J. L.
Henderson, Herbert
Hendrickson, G. L.
Hoffman, W. G.
Irvin, R. L.
Menaglia, V. A.
Neely, F. H.
Roberts, G. W.
Vogel, L. J.

ASSOCIATE MEMBERS

Dwelle, E. R.
Hunter, E. O.
Stow, F. S.
Van Epps, G. N.

ASSOCIATE

Wisecarver, T. J., Jr.

An application for reinstatement was received from Paul N. Critchlow, of Brown & Critchlow, Farmers Bank Building, Pittsburgh, and after discussion it was moved and carried that he be reinstated to membership.

The report of the Secretary showing the condition of the finances at the close of business January 31, having been audited by the Finance Committee, was approved.

The Chairman of the Finance Committee made the following appointments, subject to approval: Messrs. G. E. Dignan, F. F. Schauer and R. W. Andrews.

The Committee held its organization meeting on February 15, at which there was a discussion of the general finances of the Society and the budget

of expenditures and receipts for the present year. The Committee found the report of Mr. Fohl, Chairman of last year's Committee, quite helpful to have in estimating the business for the coming year. They submit for your approval the following budgets of expenditures and receipts:

ESTIMATED EXPENDITURES

Rent	$ 7,200.00
Meeting Expense	2,900.00
Miscellaneous Printing	700.00
Office Expense	2,000.00
Subscriptions	165.00
Auditing	225.00
Social Activities	1,300.00
Society Pins	150.00
Salaries	8,700.00
Year Book	500.00
Total	$23,840.00

ESTIMATED RECEIPTS

The revenue is derived from a list of members as of January 1, 1929:

	Resident	Non-Resident	
Members	1034	240	
Associate Members	158	21	
Associates	70	12	
Juniors	94	16	
Student Juniors	9	1	
	1365	290	—Total 1655

The total income from this scource amounts to $22,330.00

Other income derived from

Interest	$1,275.00	
Sale Society Pins	150.00	
Sale PROCEEDINGS	500.00	
		1,925.00
		$24,255.00

In making up the budget of expenses of last year's budgets, both estimated and actual were considered and, inasmuch as this apparently was a normal year, the actual expenditures were used in most cases. We began the year 1928 with unpaid bills on hand amounting to about $3,100.00. These were paid, together with current expenses, and the unpaid balance on hand, December 31, 1928, amounted to $1,700.00. This means that the budget, as presented today, will probably not amount to quite as much as estimated, as we only have $1,700.00 in unpaid bills, rather than $3,000.00, as was the case January 1, 1928.

In addition to the figures presented in this budget, the Committee has certain additions which they wish to recommend. In estimating receipts, the income from dues was figured from the list of members as of January 1, 1929. In 1928 we closed the year with six per cent. of the membership still owing dues. Believing that this same number will be unpaid at the end of the current year, the Committee feels that this amount will probably be offset by new members coming in, which have averaged 125 a year for the past five years. They have, therefore, estimated the receipts at 100 per cent. collections and have not taken into account any revenue to be derived from

new members. The other items were estimated from actual receipts last year.

The net profit from the Annual Banquet this year amounted to $632.00, which means that we have a favorable difference in the budgets, as estimated, of a little over $1,000.00.

It appears to the Committee, who made a close study of the general financial condition of the Society for the past few years, that there should be an increase in dues. Even though our budgets, as estimated, are pretty well balanced, there is an amount due the Permanent Fund, as reported by the last Committee, and if the Society continues to grow there will naturally be an increase in cost of operation. The Committee, therefore, wishes to go on record as recommending to this body that an increase in dues of $2.50 be made for Members and Associate Members and $5.00 for Associates, the understanding being that no increase be made for the Juniors and Student Juniors.

The question of an increase in dues was the first item in the report of the Finance Committee to be discussed. A suggestion was made by Mr. Skinkle that rather than increase the dues of the entire resident membership for the grades of Member and Associate Member that a geographical line be drawn whereby the increase would only include those whose office or home was within three miles of the Allegheny County Court House, the idea being that these men were in a position to take more active part in the work of the Society and make use more frequently of our club facilities. Attention was called, however, to the fact that while this is true, unfortunately a small percentage of the members, even in the downtown district, were making much use of the clubroom and other facilities and they might feel that they were being penalized within this circle.

After a thorough discussion, it was suggested that an informal poll be taken of those present as to how they felt about the increase and what amount they would suggest. It was found from this vote that the members present were unanimously in favor of a $5.00 increase. Attention was called to the fact that at the present time the Associate was paying $2.50 a year less than the Member and the Associate Member and it was felt that their dues should be increased to bring them up to at least the same amount as the higher grades. It was, therefore, recommended that in placing these figures before the Society it should be stated that the dues for all resident members, excepting Juniors and Student Juniors, be increased to $20.00 a year. A motion was made and unanimously carried that the Finance Committee be instructed to prepare a letter to be sent to the membership regarding the increase, this letter to be presented at the next meeting of the Board of Direction for their approval, after which the ballot of the Society can be taken.

The question of the budget was next discussed, and it was regularly moved and carried that the budget of expenditures and receipts, as presented by the Committee, be approved.

The Finance Committee recommended that an increase in salaries of $10.00 per month be made to the two assistants of the office. It was moved and carried that this recommendation be approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 407 during the month of January, 1929.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

The Secretary retired from the room while the election of the Secretary took place, and K. F. Treschow was re-elected as Secretary for 1929, at the salary of $5,400.00 a year.

The Secretary presented letters from the Pittsburgh Testing Laboratory, A. R. Ellis, Vice President, and the General Electric Company, W. B. Spellmire, regarding a Referendum No. 53 of the United States Chamber of

Commerce, having to do with the administration of state and local highways. Afer discussion, it was regularly moved and carried that this matter be tabled and the Secretary was instructed to write both of these gentlemen stating that due to the limited time between the meeting of the Board and the final date the ballots must be sent in, the Board did not think they could take any definite action.

Mr. Affelder brought up the question of time of the meeting of the Board of Direction, stating that he believed it would be much more convenient for most of the members to attend a noon-day meeting than at the present time—4:00 o'clock in the afternoon.

After discussion, it was regularly moved and carried that as an experiment the next meeting of the Board of Direction be called for 12:00 noon, the understanding being that the members will have lunch together and the business will be conducted immediately following the luncheon.

The meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—MINING SECTION

The annual meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Monday evening, February 25, at 8:00 o'clock, Chairman L. O. Lougee presiding, 69 members and visitors being present.

The minutes of the last meeting, held November 26, 1928, were read and approved.

The annual report of the Chairman was presented by the Secretary.

The report of the Nominating Committee was presented as follows:

"*To Members of Mining Section,*
Engineers' Society of Western Pennsylvania.

Dear Sirs—In accordance with the By-Laws of the Section, your Nominating Committee, appointed by the Chairman, has met and respectfully submit the following members as nominees for the offices of the Section for the coming year:

L. E. Young.....Chairman
G. F. Osler.....Vice Chairman
Joseph Bryan
M. E. Haworth
R. M. Black
J. F. Robinson
T. B. Sturges
.....Directors

Respectfully submitted,
W. E. Fohl, *Chairman,*
S. L. Goodale,
Graham Bright,
Nominating Committee."

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot for the officers named, who were thereupon declared elected.

No further business coming before the Section, the paper of the evening, on "Oil-Sand Mining as Practiced in France and Germany," was presented by George S. Rice, Chief Mining Engineer, U. S. Bureau of Mines, Washington, D. C.

The meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—ELECTRICAL SECTION

The annual meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers, in the Chamber of Commerce Auditorium, Tuesday, March 12, at 7:30 P. M., Chairman H. E. Dyche presiding, 170 members and visitors being present.

The minutes were approved without reading.

The annual report of the Section was read by Mr. Dyche.

The report of the Nominating Committee was presented as follows:

"*To Officers and Members, Electrical Section,*
Engineers' Society of Western Pennsylvania.

DEAR SIRS—Your Nominating Committee, appointed to nominate officers for the Electrical Section for the ensuing year, met today and nominated the following:

J. I. Alexander.....Chairman
H. E. Dyche.....Vice Chairman
Paul Caldwell
J. M. Miller
D. M. Simons
R. E. Uptegraff
J. L. McKim Yardley
.....Directors

Respectfully submitted,
A. B. STARR, *Chairman*,
L. J. LAMBERGER,
Nominating Committee."

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot for the officers named, who were thereupon declared elected.

No further business coming before the Section, the paper of the evening, on "Long-Distance Toll Cable Transmission," was presented by J. A. Cadwallader, Engineer of Transmission and Outside Plant, The Bell Telephone Company of Pennsylvania, Pittsburgh.

On motion, duly seconded and carried, the meeting adjourned at 9:20 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor "G" of the William Penn Hotel, Tuesday, May 21, at 12 o'clock, President J. N. Chester presiding, Messrs. W. L. Affelder, V. R. Covell, A. S. Davison, C. E. Lesher, C. A. Carpenter, L. E. Young, L. C. Edgar, E. L. Worthington and J. A. Hunter being present, Messrs. W. B. Skinkle, A. Stucki, G. T. Ladd, G. F. Siefers, B. R. Shover, J. I. Alexander, T. J. McLoughlin and J. F. Laboon being absent.

The minutes of the last regular meeting, held April 16, were approved without reading.

Applications from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBER

Andrews, John, Jr.

ASSOCIATE MEMBERS

Kennedy, Louis P.
Loughin, Paul R.
Lubelsky, Benjamin L.
Turner, George Walter

ASSOCIATE

Chew, Robert E.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Blaisdell, Allen Holt
Curtin, Joseph McMeen
Ellsworth, Walter E.
Hodgson, Alfred Edward
Johns, Thomas R.
Newdick, Norton A.
Leonard, R. D.
Palmer, Charles Douglas
Poling, Murray Yost
Sivitz, William Irving
Stewart, A. J.
Thomas, Roy Emil
Von Thaden, Herbert

ASSOCIATE MEMBERS

Hovey, O. W.
Parker, Herbert E.
Pote, Kenneth E.

ASSOCIATE

Haller, Fred E.

JUNIOR

MacGaugh, Myles C.

An application for transfer was received from Arch V. Ritts, 519 Oliver Building, Pittsburgh, and after discussion it was moved and carried that he be transferred to the grade of Member.

An application for reinstatement was received from Ray V. Warren, 409 Empire Building, Pittsburgh, and after discussion it was moved and carried that he be reinstated to membership.

A letter of resignation was received from George R. Johnson, Grant Building, Pittsburgh, and after discussion it was ordered accepted.

The Secretary reported the death of Julian Burdick, Brackenridge, Pa., who joined the Society March, 1924, and died April 21, 1929.

The report of the Secretary showing the condition of the finances at the close of business April 30, having been audited by the Finance Committee, was approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 225 during the month of May. Mr. Covell also reported that the new offices were well under way and would probably be ready for occupancy about June 15.

Mr. Davison, Chairman of the Entertainment Committee, reported that the Bridge Party, held May 10, had been very successful, with an attendance of 144. The Committee has just appointed sub-committees to have charge of the Boat Excursion, which will be held June 17.

Mr. Lesher, Chairman of the Finance Committee, presented a diagram, showing an increase in expenditures, receipts and membership for the past twenty years. This was prepared with the thought that it would be used in connection with a letter to be sent to the membership regarding an increase in dues, it being the opinion of the Committee that this diagram would show more clearly the necessity for an increase, and this could be supplemented by a brief letter of explanation.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

The Secretary presented a letter from W. A. Weldin, Chairman of the Special Committee, to promote the adoption of the recent report issued by the American Engineering Council on Traffic Signs, Signals and Markings. After a general discussion, it was regularly moved and carried that a suggestion be made to this Committee to the effect that they first endeavor to get in touch with the municipalities along one of the main highways, out of Pittsburgh, and center their activities on these towns. It was felt that if the larger communities, along the highways, adopted the signals and markings recommended in this report, the others would eventually fall into line. Attention was called to the fact that there was some real hard work ahead of the Committee, as some of the communities had already lined up and others were more or less influenced by manufacturers in putting in their systems.

The Secretary presented an invitation from the American Engineering Council to our Society to be represented at the Fourth Conference of Secretaries of Engineering Societies to be held in Chicago, June 6 and 7. It was moved and carried that the Secretary be instructed to attend this Conference.

The Secretary presented a letter from C. R. Sabin, Chairman of Committee "A" of the Conference of Secretaries, which Commitee has in charge the consideration of membership requirements and interchange of membership between Local Societies. Mr. Sabin's letter included a questionnaire, which first asked whether our By-Laws provided for an interchange of membership,—second, whether the Society is generally favorable to a plan of classification of societies and under what class our organization preferred to be listed. After the Secretary gave an explanation of these questions, it was regularly moved and carried that the Board go on record as being favorable to the plan of classification, and it was suggested that our Society be placed in Class "A,"—further, if such classifications are adopted, our Board would consider amending the By-Laws to conform to such requirements.

The meeting adjourned at 2 P. M.

K. F. Treschow, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section was held on Tuesday evening, May 7, in the Blue Room, William Penn Hotel, Chairman J. F. Laboon presiding, 160 members and visitors being present.

The minutes of the last meeting, held March 5, were not read.

No further business coming before the Section, the paper of the evening, "Highway Construction," was presented by Mr. Samuel Eckels, Chief Engineer, Department of Highways, Harrisburg, Pa.

The ensuing discussion was participated in by:

J. T. Campbell	C. B. Stanton
J. S. Cole	S. H. Moffett
P. J. Freeman	J. M. Rice
N. F. Brown	Major J. P. Leaf
E. N. Mattingmore	R. H. Helick
E. G. Lang	Fred Schatz
J. L. Herber	C. V. Braden

A rising vote of thanks was extended to Mr. Eckels for his very interesting paper.

The meeting adjourned at 10:35 P. M.

K. F. Treschow, *Secretary.*

STEEL WORKS SECTION

A meeting of the Executive Committee of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, William Penn Hotel, Friday afternoon, April 12, at 4:00 P. M., Chairman B. R. Shover presiding, Messrs. Stone and Whigham being present.

The Chairman stated that the meeting had been called to make plans for meetings of the Section to be held during the season 1929-30. After a general discussion of the subjects selected for the past year, which were held over, the following program was tentatively arranged:

OCTOBER 22, 1929—ALL-DAY CONFERENCE

"Methods of Budgeting in Steel Plants." By L. C. Edgar.

"Steel Plant Costs from the Standpoint of the Auditor." By W. L. Lewis, Asst. Comptroller, Bethlehem Steel Company, Bethlehem, Pa., or B. C. Moise, Vice President, National Tube Company, Pittsburgh, Pa.

"Increment Costs." By W. B. Skinkle.

FEBRUARY 25, 1930—ANNUAL MEETING

Address of Retiring Chairman.

APRIL 23, 1930—ALL-DAY CONFERENCE

"Combustion in Open Hearth Furnaces." By W. P. Chandler, Jr.

"Blas Furnace Gas for Steam Generation." By R. M. Overton.

"Open Hearth Design." By A. L. Stevens, Chicago, Ill.

The following papers were held in reserve, having been suggested for last season's meetings:

"Sheet Steel Manufacture." By Chas. R. Hook, Vice Pres. & Genl. Mgr., American Rolling Mill Co., Middleton, Ohio.

"Recuperators." By Mr. Culbertson, Chapman-Stein Company, Mt. Vernon, Ohio.

"Microscopic Study of Steel." By J. P. Gill, Vanadium Alloy Steel Co., Latrobe, Pa.

In connection with the All-Day Conferences, it was suggested that letters be sent to the executives of various industries in Pittsburgh, calling attention to these meetings and of the value to their engineers, and asking for their co-operation towards interesting the engineering departments to attend. It was further suggested that during the summer months a card index be made up of the executives and plant superintendents in this district and that selection be made from this list for the above letters.

The meeting adjourned at 5 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Parlor G of the William Penn Hotel, Tuesday, May 21, at 12:00 o'clock, President J N. Chester presiding, Messrs. W. L. Affelder, V. R. Covell, A. S. Davison, C. E. Lesher, C. A. Carpenter, L. E. Young, L. C. Edgar, E. L. Worthington and J. A. Hunter being present, Messrs. W. B. Skinkle, A. Stucki, G. T. Ladd, G. F. Siefers, B. R. Shover, J. I. Alexander, T. J. McLoughlin and J. F. Laboon being absent.

The minutes of the last regular meeting, held April 16, were approved without reading.

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ASSOCIATE MEMBERS

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Loughin, Paul R.
Lubelsky, Benjamin L.
Turner, George Walter

ASSOCIATE

Chew, Robert E.

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Hodgson, Alfred Edward
Johns, Thomas R.
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Leonard, R. D.
Palmer, Charles Douglas
Poling, Murray Yost
Sivitz, William Irving
Stewart, A. J.
Thomas, Roy Emil
Von Thaden, Herbert

ASSOCIATE MEMBERS

Hovey, O. W.
Parker, Herbert E.
Pote, Kenneth E.

ASSOCIATE

Haller, Fred E.

JUNIOR

MacGaugh, Myles C.

An application for transfer was received from Arch V. Ritts, 519 Oliver Building, Pittsburgh, and after discussion it was moved and carried that he be transferred to the grade of Member.

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A letter of resignation was received from George R. Johnson, Grant Building, Pittsburgh, and after discussion it was ordered accepted.

The Secretary reported the death of Julian Burdick, Brackenridge, Pa., who joined the Society March, 1924, and died April 21, 1929.

The report of the Secretary showing the condition of the finances at the close of business April 30, having been audited by the Finance Committee, was approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 225 during the month of May. Mr. Covell also reported that the new offices were well under way and would probably be ready for occupancy about June 15.

Mr. Davison, Chairman of the Entertainment Committee, reported that the Bridge Party, held May 10, had been very successful, with an attendance of 144. The Committee has just appointed sub-committees to have charge of the Boat Excursion, which will be held June 17.

Mr. Lesher, Chairman of the Finance Committee, presented a diagram showing an increase in expenditures, receipts and membership for the past twenty years. This was prepared with the thought that it would be used in connection with a letter to be sent to the membership regarding an increase in dues, it being the opinion of the Committee that this diagram would show more clearly the necessity for an increase, and this could be supplemented by a brief letter of explanation.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

The Secretary presented a letter from W. A. Weldin, Chairman of the Special Committee to promote the adoption of the recent report issued by the American Engineering Council on Traffic Signs, Signals and Markings. After a general discussion, it was regularly moved and carried that a suggestion be made to this Committee to the effect that they first endeavor to get in touch with the municipalities along one of the main highways, out of Pittsburgh, and center their activities on these towns. It was felt that if the larger communities along the highways adopted the signals and markings recommended in this report the others would eventually fall into line. Attention was called to the fact that there was some real hard work ahead of the Committee, as some of the communities had already lined up and others were more or less influenced by manufacturers in putting in their systems.

The Secretary presented an invitation from the American Engineering Council to our Society to be represented at the Fourth Conference of Secretaries of Engineering Societies to be held in Chicago, June 6 and 7. It was moved and carried that the Secretary be instructed to attend this Conference.

The Secretary presented a letter from C. R. Sabin, Chairman of Committee A of the Conference of Secretaries, which Committee has in charge the consideration of membership requirements and interchange of membership between Local Societies. Mr. Sabin's letter included a questionnaire, which first asked whether our By-Laws provided for an interchange of membership; second, whether the Society is generally favorable to a plan of classification of societies and under what class our organization preferred to be listed. After the Secretary gave an explanation of these questions, it was regularly moved and carried that the Board go on record as being favorable to the plan of classification, and it was suggested that our Society be placed in Class A; further, if such classifications are adopted, our Board would consider amending the By-Laws to conform to such requirements.

The meeting adjourned at 2:00 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in Room 566, William Penn Hotel, Friday, June 14, at 12:00 o'clock, President J. N. Chester presiding, Messrs. W. L. Affelder, V. R. Covell, B. R. Shover, W. B. Skinkle, J. I. Alexander and C. A. Carpenter being present, Messrs. E. L. Worthington, L. C. Edgar, G. T. Ladd, A. S. Davison, T. J. McLoughlin, L. E. Young, C. E. Lesher, J. A. Hunter, J. F. Laboon, A. Stucki and G. F. Siefers being absent.

The minutes of the last regular meeting, held May 21, were approved without reading.

Applications from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Blaisdell, Allen Holt
Curtin, Joseph McMeen
Ellsworth, Walter E.
Hodgson, Alfred Edward
Johns, Thomas R.
Newdick, Norton A.
Leonard, Raymond Davis
Palmer, Charles Douglas
Poling, Murray Yost
Sivitz, William Irving
Stewart, Arthur Jackson
Thomas, Roy Emil
Von Thaden, Herbert

ASSOCIATE MEMBERS

Hovey, O. W.
Parker, Herbert E.
Pote, Kenneth E.

ASSOCIATE

Haller, Fred E.

JUNIOR

MacGaugh, Myles C.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Criswell, John Russel
Gray, Thomas William
Holleran, Michael J.
Hulse, S. W.

ASSOCIATE

Schultz, F. G.

JUNIOR

Stevens, W. R.

The report of the Secretary, showing the condition of the finances at the close of business May 31, having been audited by the Finance Committee, was approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 190 during the month of June. Mr. Covell also reported that progress on the new offices was going along rapidly and latest indications were that we would move in about the first of July. In this connection, Mr. Covell stated that the lighting the Hotel planned to install in these rooms, while good, was not the latest type of office lighting, and that after consultation with the Duquesne Light Company, he wished to recommend that the Society purchase the most approved form of lighting and pay the difference between the cost of the Hotel lighting and that proposed by the Duquesne Light Company. Mr. Covell stated that he believed this amount

would be in the neighborhood of $75.00. After a general discussion, it was regularly moved and carried that the House Committee be authorized to install the newest form of illumination, as proposed by the Duquesne Light Company, providing the Finance Committee approved it.

The Secretary reported in behalf of the Entertainment Committee, stating that arrangements were completed for the Annual Boat Excursion to be held June 17 and the Golf Tournament to be held June 24.

The Secretary reported in behalf of the Finance Committee to the effect that a report be presented to the membership regarding dues, which report is in the process of formation. Unfortunately, the Chairman was compelled to be absent from the meeting. The suggestion was made that a Sub-Committee be appointed to approve the letter to be submitted by the Finance Committee. After discussion, it was moved and carried that the President appoint a Committee of three, of which he is to be Chairman, together with the First Vice President, W. L. Affelder, and the Senior Past President, G. T. Ladd.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and to act on any other business coming before the Committee.

The Secretary submitted a request from the Chamber of Commerce, requesting that our Society send an invitation to the American Society of Testing Materials to hold their next Convention in Pittsburgh. It was regularly moved and carried that the Secretary be instructed to write the American Society of Testing Materials, extending to them formal invitation of the Board of Direction to hold their next Convention in Pittsburgh and offering the facilities of our Society during their visit.

The Secretary presented a brief report on the Fourth Conference of Local Secretaries held under the auspices of the American Engineering Council in Chicago June 6 and 7.

The meeting adjourned at 1:15 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING

Electrical Section E. S. of W. Pa. and Pittsburgh Section A. I. E. E.

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers, in the Chamber of Commerce Auditorium, Tuesday evening, October 15, Chairman J. A. Cadwallader presiding, with 350 members and visitors being present.

The minutes of the last meeting, held March 12, were dispensed with.

No further business coming before the Society, the paper of the evening on "Making Sound Visible and Light Audible" was presented by Mr. John B. Taylor, Consulting Engineer, Central Station Dept., General Electric Co., Schenectady, N. Y. Mr. Taylor presented some very interesting experiments with light rays and the production of tone through the medium of light wave motion.

A vote of thanks was extended to Mr. Taylor for his very interesting presentation.

The meeting adjourned at 10 P. M.

K. F. Treschow, *Secretary.*

ALL-DAY CONFERENCE—MECHANICAL SECTION

An All-Day Conference of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Society of Mechanical Engineers on Tuesday, October 1, at 9:30 A. M., Mr. W. N. Flanagan presiding, 135 members and visitors being present.

The reading of the last minutes of the Section were dispensed with.

The following papers were presented:

"Industrial Power." By J. H. Lawrence, President, Thomas E. Murray, Inc., 88 Lexington Avenue, New York.

"Industrial Power From the Executive's Standpoint." By J. C. Hobbs, Supt. of Power, Diamond Alkali Co., Painesville, Ohio.

"Trend in Design and Operation of Industrial Plants With Special Reference to Size of Furnaces." By Henry Kreisinger, Combustion Engineering Corp., 200 Madison Avenue, New York, N. Y.

"Some Economic Fallacies on Isolated Plant Cost Analyses." By F. M. Van Deventer, Mechanical Engineer, H. L. Doherty & Company, 60 Wall Street, New York.

Discussion of the above papers was participated in by several.

The meeting adjourned at 4:35 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Monday evening, October 7, at 8:15 o'clock, Chairman L. E. Young presiding, with 108 members and visitors being present.

The minutes of the last meeting were not read.

No further business coming before the Section, the paper of the evening on "The Coal Areas of Alaska and Western Canada" was presented by Mr. George Watkin Evans, Consulting Coal Mining Engineer, Seattle, Washington, and was illustrated by lantern slides.

On motion duly seconded and carried, a vote of thanks was extended to Mr. Evans for his very interesting and instructive talk.

The meeting adjourned at 10:10 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Crystal Parlor of the William Penn Hotel, Thursday afternoon, September 19, at 4 o'clock, President J. N. Chester presiding, Messrs. J. I. Alexander, V. R. Covell, J. A. Hunter, C. E. Lasher, W. B. Skinkle and L. E. Young being present, Messrs. W. L. Affelder, L. C. Edgar, A. S. Davison, C. A. Carpenter, G. T. Ladd, J. F. Laboon, T. J. McLoughlin, B. R. Shover, A. Stucki, E. L. Worthington and G. F. Siefers being absent.

The minutes of the last regular meeting, held June 14, were approved without reading.

Applications from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Criswell, John Russel
Gray, Thomas William
Holleran, Michael J.
Hulse, S. C.

ASSOCIATE MEMBER

Breisky, J. V.

ASSOCIATE

Schultz, Ferdinand George

JUNIOR

Stevens, William Ronald

Applications for membership were received from the following gentlemen and their names were ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Blake, A. Wade
Herrmann, John LeRoy
Howell, Sidney Albert
MacDonald, Roland
Osbourne, Richard Barrows

ASSOCIATE MEMBERS

Cook, John Orth
Laird, James B.
Nelson, Harry Lloyd
Roberts, G. Braden

JUNIOR

Steber, Herman Louis

In response to a recent letter sent to the Junior membership a few months ago, applications for a transfer to a higher grade were received and it was moved and carried that they be made as follows:

Bickel, W. D.
Bloom, F. S.
Boyle, W. W.
Cutler, D. E.
Greg, V. V.
Hammer, L. E.
Hoffman, J. T.
Jenks, S. M.
Kelly, J. M.
Magnani, Charles
McEwen, J. D.
McQuiston, W. B.
Nourie, L. R.
Peterson, V. H.
Smyers, W. H.
Terman, M. J.
Thorn, Thos. H.
Tyler, L. P.
Whigham, Wm., Jr.

ASSOCIATE MEMBERS

Cotter, G. L. Taylor, N. C.
Wilson, C. A. McK.

Letters of resignation were received from the following, and after discussion it was ordered that they be accepted:

Burgess, E. A.	Morgan, H. W.	Stotz, J. K.
Hampton, W. M.	Peterson, J. N.	Verner, James
Hoban, C. O.	Shoemaker, L. H.	Worthington, E. L.
Hughes, G. W.	Snyder, W. T.	Ziegler, N. A.
Johnson, C. F.	Starr, C. T.	

The Secretary reported the following deaths:

Holstein, S. N.....Died July 1, 1929
Neeld, A. D.....Died November 28, 1929
Toupet, J. H.....Died January, 1929

The report of the Secretary showing the condition of the finances at the close of business August 31, having been audited by the Finance Committee, was approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 267 for the months of August and September.

The Secretary reported in behalf of the Entertainment Committee that a meeting had been called to discuss plans for the coming Annual Banquet and Ladies' Night Party, to be held the latter part of October. Plans have been completed for the Golf Tournament to be held at the Westmoreland Country Club, Monday, September 23, and an announcement has been mailed.

Mr. Lesher, Chairman of the Finance Committee, reported that in accordance with action taken at the May meeting of the Board, a letter had been drawn up by the Committee, together with a study of curves, showing an increase in expenditures and receipts to be submitted to the membership for a letter ballot on an increase in dues. The Secretary then read the letter prepared by the Committee and after discussion it was regularly moved and carried that the Secretary be authorized to submit this letter to the membership for their vote, in accordance with the By-Laws. The Chairman further reported that due to the fact that we were about $900 behind in receipts for dues and paid for one issue more of the PROCEEDINGS to September 1st, than we had paid last year, our finances were practically exhausted in the General Fund. This means that we have approximately $2000 less in the General Fund than we had the same time last year and is mostly accounted for by the above mentioned item. After a general discussion, it was regularly moved and carried that the Finance Committee be authorized to borrow $1500 from the Reserve Fund, deposited in the Fidelity Title and Trust Company, in accordance with the By-Laws, to be used for General Fund purposes and to reimburse the fund after the first of the coming year.

The Membership Committee held one meeting to go over applications received since last meeting of the Board and to act on any other business coming before the Committee.

The Secretary reported in behalf of the Publication Committee that plans for the Lecture Course had been completed and that announcements were being mailed at this time. The Chairman of the Committee bespeaks the co-operation of each member of the Board in assisting to dispose of as many of the strip tickets as possible.

The Secretary presented a letter from the American Society of Mechanical Engineers, inviting our Society to appoint two official delegates to represent us at the celebration of their Fiftieth Anniversary to be held in April, 1930. After discussion, it was accordingly moved and carried that the Presi-

dent be authorized to appoint these delegates. Mr. Chester stated that, with the approval of the Board, he would prefer to delay the appointment of delegates in order to permit the next President to make them during his administration.

The President announced that he was leaving the city the latter part of September on an extended trip, which would include his attendance at the World Engineering Congress to be held in Tokio, Japan, and as he would be absent during the remainder of his term of office, would present his resignation, if the Board desired. It was regularly moved and carried that the President be continued in office until his term regularly expires and that the Senior Vice President, Mr. W. L. Affelder, preside at meetings of the Board and the Society for the balance of the term.

The President announced that in accordance with Article V, Section IV, of the By-Laws he wished to announce the appointment of the following Nominating Committee for the coming year: A. R. Raymer, Chairman; J. A. Hunter, W. E. Fohl, E. D. Leland, Richard Khuen, Jr.

The Secretary raised the question of the Board considering a suitable celebration of the Society's Fiftieth Anniversary, which will be held in 1930. After discussion, it was regularly moved and carried that this matter be brought up as regular business at the next meeting of the Board of Direction. Mr. Alexander brought up the matter of the Light's Golden Jubilee, which is being celebrated throughout the country, and stated that elaborate plans were being made for Pittsburgh's part in this celebration and suggested that the Society co-operate in some way. After discussion, it was regularly moved and carried that the Secretary be authorized to write the President of the Chamber of Commerce, offering our co-operation.

The meeting adjourned at 1:30 P. M.

K. F. Treschow, *Secretary.*

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